Upper Assiniboine River Basin Study

Environment Canada Environnement Canada

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101-01925/

Upper Assiniboine River Basin Study

Appendix A

Drainage and Flood Control Committee Report

August 2000

Executive Summary

This report describes the work, findings, conclusions and recommendations of the Drainage and Flood Control Committee of the Upper Assiniboine River Basin Study. The central focus of this Committee was to examine the effects of land cover changes on the runoff regime in the Basin. Of particular interest was the drainage of wetlands associated with agricultural development and practises in the Basin.

The principal conclusions of this Committee were:

- Climatic processes dominate the generation of major flood events;
- The greatest relative impact of drainage of wetlands is during moderate runoff events, with the effect diminishing for increasingly larger flood events;
- Drainage of wetlands has little effect on major flood events;
- Effects of land cover changes and wetland drainage in the Basin could not be quantified, but a trend of increasing runoff volume was detected; and
- Increased runoff volumes into lakes gives rise to management issues and reduces operational flexibility of reservoirs.

The large snowmelt runoff event of 1995 precipitated demands for an investigation into the effect of agricultural drainage on flows in the Assiniboine River. The Committee found that the high flows of 1995 can be primarily attributed to a combination of meteorological events, namely wet antecedent conditions, an above-normal snowpack, and a mid-April rainstorm which contributed additional runoff water and caused rapid melting of the snowpack. This rapid melt across much of the Basin resulted in an unusual hydrologic condition: the nearly coincident peak flows on the Assiniboine and Whitesand rivers at Kamsack as well as on smaller local tributaries between Kamsack and Shellmouth Dam. Lake of the Prairies significantly reduced flow rates and water levels downstream of the Shellmouth Dam from what would have occurred had the dam and reservoir not been in place.

Drainage of wetlands and changes to land cover over time by landowners have been in response to economic pressures, government policies and legislation, and the climate of the Basin. The net effect of these pressures was examined in the changes to Basin land cover since the 1950s. Information sources were Statistics Canada, topographic maps, and previous studies of localized areas in the Basin. The wetland loss within certain areas of the Basin is consistent with the range of accepted literature values of about 45 percent, although in highly affected areas, the number of wetlands affected by drainage may exceed 80 percent. It appears that in some areas of intense drainage activity, most of the drainage occurred prior to 1980 and that recent efforts are primarily for the maintenance and improvement of the existing drainage systems. In other areas, new, unauthorized drainage of temporary and seasonal wetlands using contour ditches and V-ditching has continued since 1980. These activities generally increase following wet years and are most prevalent in areas of high density of undrained wetlands and on lands being incorporated into larger farm units. While studies of certain areas were available for review in this report, there is no practical, cost-effective method of detecting and quantifying wetland loss due to drainage on a Basin scale at this time.

The effect of natural and drained wetlands on downstream flows was analyzed on a conceptual basis. Natural wetlands retain runoff which will subsequently evaporate. Drainage of wetlands moves runoff into the stream network, reducing the opportunity for evaporation. Thus, drainage of wetlands will, in general, increase runoff volumes. The greatest relative impact of drainage on flows is during moderate runoff events. The effect of wetland drainage diminishes for increasingly larger flood events. In general, drainage projects which can regulate outflows will have less effect on downstream peak flows than projects which do not regulate outflows.

Hydraulic models are available to assess the effects on runoff of individual, small scale drainage projects in small watersheds. However, it is not practical at this time to assess the effects of large numbers of undocumented drainage projects using hydraulic models on a watershed the size of the Basin.

The landscape of the Basin has undergone extensive changes over the past century. The Basin was once comprised of a mix of natural prairie and parkland. Now the most prevalent land use in the Basin is annual crop production. From the Statistics Canada Census information dating back to the 1950s, the improved area has increased from 56 percent to 77 percent of the reported land area. The unimproved land area has decreased from 44 percent to 23 percent. This unimproved area is comprised primarily of woodlands, native grasslands, and wetlands. Associated with the increase in area used for agriculture is an increase in the number of roads in the Basin.

A comparison of mapped wooded area in the 1950s with that mapped more recently showed that many small, isolated woodland stands have been eliminated, while larger stands have been less affected. Various sources of data on wetland numbers, unimproved land area, and improved land area over time indicate the rate of conversion of unimproved land into agricultural production has slowed over the past two decades.

Hydrologic analysis of streamflow records in the Basin indicates that runoff volumes have been increasing. The Committee concluded that changes in Basin land cover, including loss of wooded area, loss of wetlands, improved drainage network, and increased road development, have resulted in increased runoff volumes over what would have occurred naturally. However, it is not possible to determine the hydrologic effect of individual land cover changes on runoff by examining only recorded streamflow data.

A number of modeling approaches aimed at the assessment of land cover changes and drainage of wetlands are reviewed in this report. Previous studies were examined, particularly those with application to the Basin. Those studies suggested that drainage of wetlands will increase runoff volumes but also suggested that peak flows can be reduced, increased, or remain unaffected, depending on a number of factors. The review of modeling approaches concluded that the most appropriate type of model for assessing the impact of both land cover change and drainage of wetlands would be a vertical water balance, hydrologic model. Of the models available, SLURP, developed by the National Water Research Institute (NWRI), was selected for application to the Basin.

The application of the SLURP model was successful in modeling flows using the current land cover data for 1995-1997 at five locations within the Basin, all of which have large drainage

areas. The modeling exercise demonstrated that geographic information system methods are able to generate land cover data required for semi-distributed hydrologic models. Modeling also demonstrated the successful application of digital elevation modeling to generate the topographic data required for hydrologic modeling. The Committee requested NWRI upgrade the model to account for wind redistribution of snow and better simulation of snowmelt water infiltration into frozen soils. While these upgrades significantly improved the model's performance, calibration of the model to observed flows at locations with smaller drainage areas was not satisfactory, likely due to the averaging of land cover parameters over the entire Basin. The SLURP model with the current suite of six land cover classes as currently calibrated was not able to reliably assess the effect of changes to individual land cover classes on Basin hydrology.

The Committee also examined the issues of flood damages and lake level management in the Basin. While flood events are largely natural phenomena, flood damages result when inappropriate land uses or developments are located in flood prone areas. In addition to agricultural land adjacent to streams and waterbodies throughout the Basin, flood prone areas include various lake and reservoir shorelines and several small communities. In some situations, engineering works may be the only method of reducing the risk of flood damages to existing developments in flood prone areas. However, long-term risks and costs of flood damage can be minimized by ensuring only compatible land use and development occur in flood prone areas.

Multiple interests in the use of lakes and reservoirs have resulted in conflicts over water level management and the operation of outlet control structures. In general, limited outlet or downstream channel capacity constrains lake level management. Drainage of wetlands upstream of lakes and reservoirs will increase runoff volumes into those waterbodies which can further reduce the operating flexibility.

The recommendations of the Committee are summarized below.

Watershed management plans should promote the retention of existing natural wetlands where those wetlands provide flood control benefits by controlling snowmelt runoff into the stream network. Proposed drainage projects should be reviewed and approved in accordance with current legislation and within the context of a local watershed plan which considers the impacts at downstream locations of existing, proposed and potential projects. These watershed plans should also include operating guidelines for controlled drainage works and backflood projects so that downstream damages are minimized.

Best management practices which reduce runoff rates and volumes should be promoted. Drainage projects should incorporate outflow control mechanisms. Other such best management practices include conservation tillage and establishment of permanent cover.

Water management agencies should expand public education efforts to promote awareness of the hydrologic processes that lead to large floods, as well as the operation and effect of water control projects on flow rates and water levels.

A new, effective regulatory framework for drainage should be established which takes into account the resources and expertise required for proper review and enforcement. Any

environmental, social, or economic programs or policies to address drainage should consider the economic and other factors faced by producers in their decisions whether or not to drain wetlands.

The process for zoning or other development controls should be reviewed to ensure only appropriate developments take place within flood-prone areas. Similarly, compatible land use practices should be encouraged in flood-prone areas to reduce potential flood damage to agricultural lands and urban developments located adjacent to streams and waterbodies.

Specific management issues at several lakes require that both structural and non-structural measures be investigated to improve operational flexibility of dams in the Basin.

A number of areas were identified for further study or research. Remote sensing technology for application to detection of wetland drainage in the Canadian Prairies needs to be developed. Watershed modeling tools which can be used by provincial regulatory agencies to assess the impact of drainage projects on large scale watersheds also need to be developed. Research agencies should continue investigations into the relationship between snowmelt runoff and agricultural practices such as stubble management and conversion to permanent cover. Research should continue into the development of watershed models with the aim of improved simulation of hydrologic processes on the Canadian Prairies such as variable contributing area and wetland storage. Finally, further field work is required be better define the relationship between wetland area and volume developed in this Study.

Water management agencies should continue assessing the hydrologic effects of wetland drainage and land cover change in the Basin with the knowledge base developed in this Study. Agencies also need to apply modeling tools to assess the impact of drainage projects within smaller watersheds and to develop guidelines for assessing drainage project proposals.

Agencies which develop and use wetland databases should work together to find common standards for data collection, interpretation, and definition of various wetland classes.

Acknowledgments

This report is the result of the efforts of many individuals. The work of the Committee was coordinated by Co-chairs Bob Harrison, Manitoba Conservation (MC), Doug Johnson, Sask Water (to June 1998), and Bart Oegema, Sask Water (since June 1998). Serving on the Committee were Jim Waggoner, Sask Water; Ron Woodvine, PFRA; Larry Wiens, Environment Canada; Adam Schmidt, Saskatchewan Environment and Resource Management; Brad Uhrich, Ducks Unlimited Canada; Rob Kirkness, Sask Water; and Phil Weiss, Manitoba Intergovernmental Affairs.

Analysis using GIS and Digital Elevation Models for use in the SLURP Model was provided by Lyle Boychuk, Ghislain Prince, and Patrick Cherneski, all of PFRA. Ron Hopkinson of Environment Canada compiled the meteorologic data used in the model.

Advice on application of the SLURP model was provided by research scientists at the National Water Research Institute in Saskatoon; Al Pietroniro, John Pomeroy, and Raoul Granger. Modifications to the SLURP coding were ably handled by Tom Brown, P.Eng.

While this report is the result of the combined efforts of all those on the Committee, both in its drafting and editing, the contributions of certain individuals should be acknowledged. Dave Barisow of Sask Water and Jim Rogers of Environment Canada contributed the background material for Sections 4.2 and 4.4 respectively. Gary Coghill of Saskatchewan Agriculture and Food provided background material for Section 5.1. Rob Kirkness did much of the research and analysis that forms the basis of Sections 5.2 and 6.1. Lyle Boychuk assembled the GIS and DEM databases and did much of the analysis in Sections 5.3 and 5.4, and portions of Section 7.2. Larry Wiens carried out much of the analysis of wetland storage contained in Section 5.4 and the review of previous studies detailed in Section 6.3. Rob Kirkness and Bob Harrison collaborated on the analysis contained in Section 6.2. Bart Oegema prepared much of the material found in Section 6.4 and carried out the modeling work described in Chapter 7.

Table of Contents

Executive Summary i

Acknowledgments v

List of Figures xi

List of Tables xvi

1 Introduction 1
- 1.1 Background 1
- 1.2 The Study 3
  - 1.2.1 Study Organization 3
  - 1.2.2 Drainage and Flood Control Committee 4
- 1.3 Report Outline 4

2 Basin Description 5
- 2.1 Physical and Demographic Features 5
- 2.2 Climate 7
  - 2.2.1 Precipitation 7
  - 2.2.2 Evaporation 10
  - 2.2.3 Transpiration 11
- 2.3 Water Resources 11
  - 2.3.1 Groundwater 11
  - 2.3.2 Wetlands 11
  - 2.3.3 Surface Runoff 12
- 2.4 Water Resource Projects 14
  - 2.4.1 Fishing Lake 14
  - 2.4.2 Theodore Reservoir 14
  - 2.4.3 Yorkton South Complex 17
  - 2.4.4 Good Spirit Lake 19
  - 2.4.5 Shellmouth Dam and Lake of the Prairies 20

3 Issues 23
- 3.1 Major Floods 23
  - 3.1.1 The 1995 Flood 23
  - 3.1.2 The 1922 Flood 25
- 3.2 Wetland Drainage 27
- 3.3 Land Cover Changes 28
- 3.4 Flooding 29
- 3.5 Lake Management 29
  - 3.5.1 Fishing Lake 29
  - 3.5.2 Good Spirit Lake 30
  - 3.5.3 Lake of the Prairies 30

4 Drainage History 32
4.1 Introduction 32
4.2 Saskatchewan 33
4.3 Manitoba 36
4.4 Interprovincial 38
4.5 Current Inventory 40
4.5.1 Saskatchewan 40
4.5.2 Manitoba 42
4.6 Summary 42

5 Land Cover 44
5.1 Introduction 44
5.2 Agricultural Land Cover 45
5.3 Woodlands 47
5.4 Water and Wetlands 52
5.4.1 Data Sources 52
5.4.2 Current Spatial Distribution 54
5.4.3 Trend Analysis in Spatial Distribution at Sample Sites 56
5.4.3.1 1995 Ducks Unlimited Analysis 56
5.4.3.2 1998 Ducks Unlimited Analysis 58
5.4.3.3 1994 Sask Water Analysis 59
5.4.4 Area-Volume Relationship for Prairie Wetlands 60
5.4.4.1 Study Data 60
5.4.4.2 Analysis and Conclusions 61
5.4.4.3 Comparison with a Previous Study 66
5.4.4.4 Application to Basin 69
5.5 Summary 70

6 Effects of Drainage and Land Cover Change on Runoff 72
6.1 Effects of Land Cover Changes and Agricultural Practices 72
6.1.1 Physical Processes 72
6.1.2 Application to Producers 74
6.1.3 Land Cover and Snowmelt Runoff Research 74
6.1.4 Application in the Basin to Determine Potential Effects 75
6.1.5 Summary 77
6.2 Streamflow Analysis 78
6.2.1 Introduction 78
6.2.2 Analogue Years 78
6.2.3 Mass Curve Analysis 81
6.2.3.1 Derivation of Mass Curves 83
6.2.3.2 Analysis of Stationarity 86
6.2.3.3 Analysis of Trend 89
6.2.3.4 Summary 90
6.2.4 Sub-Watershed Travel Times 90
6.2.5 Regression Analysis 91

6.2.5.1 Split Sample Analysis 91
6.2.5.2 Inclusion of Land Cover Index 92
6.2.5.3 Mass Curve Analysis 95
6.2.5.4 Conclusions of Regression Analysis 98
6.2.6 Summary of Streamflow Analysis 98
6.3 Drainage Area Analysis Techniques 98
6.3.1 Methodology 99
6.3.2 Application to the Basin 101
6.3.2.1 1983 Saskatchewan Environment Study 101
6.3.2.2 1984 PFRA Study 103
6.3.3 Summary 105
6.4 Storage and Hydraulic Routing Analysis Techniques 105
6.4.1 Routing Methods and Models 105
6.4.2 Application of Routing Methods 106
6.4.2.1 Applications in the Great Plains 106
6.4.2.2 Applications in the Basin 107
6.4.2.3 Application to Wetlands 108
6.4.3 Summary and Conclusions 114
6.5 Vertical Water Balance Method 115
6.5.1 Model Search 115
6.5.2 Model Selection 116
6.5.2.1 Criteria 116
6.5.2.2 Selection 119

7 Hydrologic Modeling 122
7.1 Model Development and Upgrades 122
7.2 Data Compilation 122
7.2.1 Selection of Study Period 122
7.2.2 Selection of Watersheds for Modeling Purposes 123
7.2.3 Land Cover 125
7.2.4 1990s Land Cover Data Set 127
7.2.5 Historic Land Cover Data 128
7.2.6 Land Cover Data Used in SLURP 131
7.2.7 Digital Elevation Model 132
7.2.8 Generation of Physiographic Data 132
7.2.9 Physiographic Data Used in SLURP 134
7.2.10 Meteorologic Data 135
7.2.11 Hydrologic Data 142
7.3 Model Application 143
7.3.1 Physical Process Parameters 143
7.3.1.1 Land Cover Parameters 143
7.3.1.2 Treatment of Controlled Lakes 151
7.3.1.3 Parameters for Routing Between ASAs 152
7.3.2 Calibration and Verification Process 153
7.3.3 Calibration and Verification Results 153

7.3.1.1 Land Cover Parameters 143
7.3.1.2 Treatment of Controlled Lakes 151
7.3.1.3 Parameters for Routing Between ASAs 152
7.3.2 Calibration and Verification Process 153
7.3.3 Calibration and Verification Results 153
7.3.3.1 Model Results for 1994 161
7.3.3.2 Other Stations 164
7.3.4 Sensitivity Testing and Results 174
7.4 Chapter Summary and Conclusions 187
7.4.1 Modeling Findings 187
7.4.2 Recommendations for Hydrologic Model Development 187

8 Conclusions and Recommendations 189
8.1 Major Floods 189
8.2 Wetland Drainage 190
8.3 Effect of Wetland Drainage on Basin Hydrology 193
8.4 Land Cover Change 195
8.5 Effect of Land Cover Change on Basin Hydrology 195
8.6 Flooding 197
8.7 Lake Management 198

References 199

Appendix:

I. ASA Physiographic Parameters Used in SLURP

List of Figures

Figure 1.1 Upper Assiniboine River Basin 2

Figure 2.1 Ecoregions in the Upper Assiniboine River Basin 6

Figure 2.2 Hydrologic Cycle Diagram 8

Figure 2.3 Monthly Precipitation at Yorkton 9

Figure 2.4 Total Annual Precipitation at Yorkton 9

Figure 2.5 Assiniboine River at Kamsack 13

Figure 2.6 Spirit Creek near Buchanan 13

Figure 2.7 Annual Runoff Volumes Assiniboine River near Russell 1913 to 1999 15

Figure 2.8 Annual Peak Flows Assiniboine River near Russell 1913 to 1999 16

Figure 2.9 Yorkton South Complex 18

Figure 2.10 Aerial View of Shellmouth Dam 22

Figure 3.1 Lake of the Prairies Inflows, 1922 and 1995 Discharge Hydrograph Comparison 26

Figure 3.2 Aerial View of Typical Conditions during 1995 Flood 26

Figure 5.1 Agriculture Statistics for 1956 46

Figure 5.2 Agriculture Statistics for 1996 47

Figure 5.3 Local Watersheds 49

Figure 5.4 Locations of Wetlands Studies 57

Figure 5.5 Langenburg Land Use 1957 59

Figure 5.6 Langenburg Land Use 1989 60

Figure 5.7 Area-Volume Relationship for Prairie Wetlands 65

Figure 5.8 Comparison of Wetland Area-Volume Relationship Results 67

Figure 5.9 Cumulative Basin Wetland Area and Volume 69

Figure 6.1 Land Use Scenario for Higher Runoff Potential 76

Figure 6.2 Land Use Scenario for a Lower Runoff Potential 76

Figure 6.3 Hydrograph Comparison Assiniboine River at Kamsack for 1948 and 1997 80

Figure 6.4 Hydrograph Comparison Assiniboine River at Kamsack for 1971 and 1985 81

Figure 6.5 Location Map of Hydrometric Stations 82

Figure 6.6 Mass Curve of Spring Peak Flows 84

Figure 6.7 Mass Curve of Spring Volumes 85

Figure 6.8 Improved Area as Percent of Total Rural Municipality 88

Figure 6.9 Assiniboine River at Kamsack Spring Runoff Volumes Estimated by Split Sampling Techniques 93

Figure 6.10 Percent Improved Area Assiniboine River Basin above Kamsack 94

Figure 6.11 Assiniboine River at Kamsack Spring Runoff Volumes Predicted by use of Land Cover Index 96

Figure 6.12 Assiniboine River at Kamsack Mass Curve Spring Runoff Volume 97

Figure 6.13 Wetland Drainage - High Initial Water Level Scenario 109

Figure 6.14 Wetland Drainage - Low Initial Water Level Scenario 110

Figure 6.15 Wetland Drainage - Outlet with Culvert Scenario 112

Figure 6.16 Wetland Drainage - Outlet with Gated Culvert Scenario 113

Figure 7.1 Current ASAs 123

Figure 7.2 Thematic Generalization of WGTPP Data for SLURP 128

Figure 7.3 Daily Precipitation 137

Figure 7.4 Daily Temperature 139
Figure 7.5 Daily Dew Point 140
Figure 7.6 Daily Sunshine 141
Figure 7.7 Assiniboine River near Sturgis - 1995 155
Figure 7.8 Whitesand River near Canora - 1995 155
Figure 7.9 Assiniboine River at Kamsack - 1995 156
Figure 7.10 Shell River near Inglis - 1995 156
Figure 7.11 Assiniboine River near Sturgis - 1996 157
Figure 7.12 Whitesand River near Canora - 1996 157
Figure 7.13 Assiniboine River at Kamsack - 1996 158
Figure 7.14 Shell River near Inglis - 1996 158
Figure 7.15 Assiniboine River near Sturgis - 1997 159
Figure 7.16 Whitesand River near Canora - 1997 159
Figure 7.17 Assiniboine River at Kamsack - 1997 160
Figure 7.18 Shell River near Inglis - 1997 160
Figure 7.19 Assiniboine River near Sturgis - 1994 162
Figure 7.20 Whitesand River near Canora - 1994 162
Figure 7.21 Assiniboine River at Kamsack - 1994 163
Figure 7.22 Shell River near Inglis - 1994 163
Figure 7.23 Assiniboine River at Shellmouth - 1994 164
Figure 7.24 Assiniboine River at Shellmouth - 1995 165
Figure 7.25 Assiniboine River at Shellmouth - 1996 165
Figure 7.26 Assiniboine River at Shellmouth - 1997 166

Figure 7.27 Crooked Hill Creek near Canora - 1997 167
Figure 7.28 Stony Creek near Kamsack - 1995 167
Figure 7.29 Stony Creek near Kamsack - 1996 168
Figure 7.30 Stony Creek near Kamsack - 1997 168
Figure 7.31 Smith Creek near Marchwell - 1995 169
Figure 7.32 Smith Creek near Marchwell - 1996 169
Figure 7.33 Smith Creek near Marchwell - 1997 170
Figure 7.34 Willow Brook near Willowbrook - 1995 170
Figure 7.35 Willow Brook near Willowbrook - 1996 171
Figure 7.36 Willow Brook near Willowbrook - 1997 171
Figure 7.37 Spirit Creek near Buchanan - 1995 172
Figure 7.38 Spirit Creek near Buchanan - 1997 172
Figure 7.39 Conjuring Creek near Russell - 1995 173
Figure 7.40 Conjuring Creek near Russell - 1996 173
Figure 7.41 Conjuring Creek near Russell - 1997 174
Figure 7.42 Crooked Hill Creek near Canora - 1994 175
Figure 7.43 Crooked Hill Creek near Canora - 1995 176
Figure 7.44 Crooked Hill Creek near Canora - 1996 176
Figure 7.45 Crooked Hill Creek near Canora - 1997 177
Figure 7.46 Assiniboine River near St Lazare - 1994 178
Figure 7.47 Assiniboine River near St Lazare - 1995 178
Figure 7.48 Assiniboine River near St Lazare - 1996 179
Figure 7.49 Assiniboine River near St Lazare - 1997 179

Figure 7.50 Stony Creek near Kamsack - 1994 180
Figure 7.51 Stony Creek near Kamsack - 1995 180
Figure 7.52 Stony Creek near Kamsack - 1996 181
Figure 7.53 Stony Creek near Kamsack - 1997 181
Figure 7.54 Crooked Hill Creek near Canora - 1994 182
Figure 7.55 Crooked Hill Creek near Canora - 1995 183
Figure 7.56 Crooked Hill Creek near Canora - 1996 183
Figure 7.57 Crooked Hill Creek near Canora - 1997 184

List of Tables

Table 2.1	Average Climate Data	10
Table 2.2	Yorkton South Complex	19
Table 3.1	Estimated Probabilities of Recurrence - 1995 Peak Flows	24
Table 4.1	Active Saskatchewan C&D Authorities in the UARB	40
Table 5.1	Comparison of the Average Farm for 1956 and 1996	46
Table 5.2	Woodland Trends - Historical Comparison	48
Table 5.3	Woodland Trends - Woodland Loss	48
Table 5.4	Woodland Trends - Pattern	51
Table 5.5	Wetland Features - Basin Summary	54
Table 5.6	Wetland Features - Distribution	55
Table 5.7	Statistical Description of Wetland Data Provided by PFRA and DU	61
Table 5.8	Results for Small Wetlands (Under 10 ha)	63
Table 5.9	Results for Large and Small Wetlands	64
Table 5.10	Comparison Between the Accepted Results for Small Wetlands and the Results of the 1967 Iowa Study	68
Table 6.1	Comparison of Assiniboine River at Kamsack for 1948 and 1997	79
Table 6.2	Comparison of Assiniboine River at Kamsack for 1971 and 1985	79
Table 6.3	Hydrometric Gauging Station Information	82
Table 6.4	1990s Land Covers	83
Table 6.5	Mass Curve Correlation Coefficient for Entire Period of Record	86
Table 6.6	Watershed Representative Rural Municipality Data	87

Table 6.7 Mass Curve Correlation Coefficients for the Period 1975 to 1995 89

Table 6.8 Mass Curve Polynomial Chi-squared Parameter 89

Table 6.9 List of Hydrometric Gauging Stations Examined for Changing Travel Times .. 91

Table 6.10 Model Selection Summary Table 121

Table 7.1 ASA Areas 124

Table 7.2 NTS Detected Errors 129

Table 7.3 1990s Land Cover Areas by ASA 131

Table 7.4 Physiographic Parameters Required for SLURP 133

Table 7.5 ASA Latitude and Elevation 134

Table 7.6 Climate Stations with Daily Precipitation 136

Table 7.7 Climate Stations with Daily Average Temperature 138

Table 7.8 Hydrometric Stations in the Upper Assiniboine River Basin 142

Table 7.9 Granger Evapotranspiration Parameters 144

Table 7.10 Canopy Parameters 145

Table 7.11 Rain/Snow Division Temperatures 146

Table 7.12 Snowmelt Parameters 146

Table 7.13 Overland Roughness Parameters 147

Table 7.14 Blowing Snow Parameters 148

Table 7.15 Frozen Soil Infiltration Parameters 149

Table 7.16 Fast Store Tank Parameters 149

Table 7.17 Slow Store Tank Parameters 150

Table 7.18 Selection for Groundwater Percolation to Deep Aquifers 150

Table 7.19 ASA Routing Parameters 152

Table 7.20 1995 Calibration Results 154
Table 7.21 1996 Calibration Results 154
Table 7.22 1997 Verification Results 154
Table 7.23 1994 Calibration Results 161
Table 7.24 Verification Results - Assiniboine River at Shellmouth 164
Table 7.25 Sensitivity Testing - Land Cover Change (percent) 185
Table 7.26 Sensitivity Testing - Land Cover Change in Square Kilometres 186

1 Introduction

The governments of Saskatchewan, Manitoba and Canada agreed to undertake a comprehensive water management study (the Study) of the upper Assiniboine River basin in eastern Saskatchewan and western Manitoba (the Basin) in 1996. The Study area includes all of the Assiniboine River basin in Saskatchewan and Manitoba to the confluence with the Qu'Appelle River as shown in Figure 1.1.

The Study was initiated in response to continued conflicting views held by Basin residents over water management and the public demand for resolution of those water management issues. Water related issues in the Basin include: the drainage of agricultural lands and associated downstream impacts, the loss of wetland habitat and functions, recurrent flooding problems, water supply concerns, mechanisms for resolving inter-provincial water-related issues, and water quality problems linked to natural conditions and human activity. The Study was to develop a water management framework to guide future water management in the Basin.

This report outlines the investigations, findings and recommendations associated with the issues related to land drainage and flooding.

1.1 Background

Settlement and subsequent agricultural development within the Basin began in the late 1800s and continued with increasing intensity into the early 1900s. Besides the initial breaking of prairie for cultivation, some clearing of brush and trees was undertaken along with a limited amount of small-scale drainage.

The geomorphology of the Basin is characterized by numerous shallow potholes or sloughs, often less than 10 metres in diameter and less than one metre in depth. These potholes, in some portions of the Basin cover 10 to 20 percent of the landscape. Many of the potholes are very shallow and only retain spring runoff for a limited period of time. Often these temporary wetlands are perceived to limit agricultural activity and due to their shallow depth they can be easily drained.

The period following the Second World War saw the advent of larger, more efficient farm machinery and its subsequent introduction to western Canadian agriculture. With the increase in farm mechanization, greater areas of native parkland habitat, including native grasses, wetlands, brush and trees were cleared. Larger, more ambitious drainage works, were constructed, making large tracts of land more suitable for cultivation. As more agricultural producers saw the advantages to be gained by putting unproductive land into production, activity in land clearing and slough drainage proliferated throughout the Basin. Thus, at present, land cover and land use within the Basin has been altered considerably from what it was in the early stages of settlement. The present economics of dry land farming generally stipulate the need for a large land base. The relatively short growing season within the Basin dictates a condensed planting period. These factors necessitate the use of large agricultural equipment, which is poorly suited to

navigating around potholes. Furthermore, the potholes are usually dry by mid summer. Thus, most landowners feel the potholes are an impediment to efficient and economical crop production.

Many farmers look to drainage schemes to eliminate the sloughs. Shallow sloughs can be easily drained with inexpensive V-ditching equipment. Often, temporary ditches are constructed in late fall after harvest. During spring runoff, the water drains from the potholes via the V- ditches. After runoff, the ditches are closed and cultivated and the landscape is prepared for seeding.

Figure 1.1
Upper Assiniboine River Basin

Residents downstream of drainage activity perceive that they receive more water than would be the case under natural conditions. They are forced to either undertake their own drainage works to pass the water along, or in cases where this is not possible, practical, or desirable, they retain the extra water which may reduce their productive land base. The initiation of action through the responsible provincial regulator against upstream contributors (if their works are unauthorized) is often a last resort.

Drainage concerns have been a long-standing and contentious issue between Manitoba and Saskatchewan residents, especially in the Russell/Langenburg area over the past 20 years. On several occasions this interprovincial drainage issue has been referred to the Prairie Provinces Water Board, an agency established to address interprovincial water management issues. However, no acceptable resolution has yet been reached within that forum. When an exceptionally high spring runoff in 1995 caused flooding throughout the Basin, downstream Assiniboine River valley land owners in Manitoba reiterated a long-standing criticism that flooding in their area was significantly magnified due to drainage of wetlands in the upper reaches of the Basin.

1.2 The Study

In July 1995, officials from the governments of Manitoba and Saskatchewan met to discuss inter-provincial drainage issues. These discussions resulted in a Memorandum of Understanding between Manitoba, Saskatchewan, and Canada in October 1996 to undertake a comprehensive study of water management issues in the Basin. The Study was designed to develop key information upon which water management decisions can be based.

1.2.1 Study Organization

The Memorandum of Understanding between the federal and two provincial governments provided for the establishment of several committees to address the many facets of the overall Study. These Committees included the technical committees of Drainage and Flood Control, Water Supply and Use, Wetlands, Water Quality, and GIS and Data Standards. In addition, two support committees were established. These were the Communication and Strategies committees.

The wide variety of water management issues within the Basin, the deeply rooted views held by many of the Basin residents, and the immediacy of the problems, reinforced the importance of ensuring public awareness and participation in the process. Thus, local watershed committees were established to provide regular input and direction to the Study, bring public concerns and issues to the Study, and to take information back to the communities they represented.

A moratorium on any new drainage projects was put into effect in the Saskatchewan and Manitoba portions of the Basin for the duration of the work of the technical committees. The moratorium was intended to maintain constant conditions throughout the Basin. It was administered by the regulatory water management agencies of the two provinces, outside the context of the Study.

1.2.2 Drainage and Flood Control Committee

The Drainage and Flood Control Committee (DFCC) was specifically charged with the task of determining the extent that the Basin landscape has changed because of wetland drainage, clearing of bush, and breaking of grasslands, and evaluating the impacts of these land use changes on the streamflow within the Basin.

The terms of reference of the DFCC were to:

- Determine and quantify changes in land cover and depressional storage within the Basin;
- Evaluate the impacts of land use and land cover changes on the Basin hydrology;
- Investigate means to mitigate impacts which may be identified; and
- Investigate other flooding issues which may be identified.

The DFCC's work involved the development of models, tools and acquisition of databases to quantify and assess the hydrologic impacts of land use and land cover changes within the Basin. It was expected that both basin-wide and sub-basin computer models would be developed. Although the DFCC had its own specific goals, the committee was also required to support the other committees in the Study by providing hydrological expertise, technical support and information as required.

1.3 Report Outline

Following this introductory chapter, Chapter 2 provides a description of the Basin from a hydrologic perspective and discusses the dominant hydrologic processes in the Basin. Chapter 2 also discusses the five major lakes and water storage projects within the Basin. Chapter 3 describes the issues and their specific backgrounds.

Chapter 4 reviews the history of drainage regulation and development in both Saskatchewan and Manitoba and presents a current inventory of organized drainage projects. Also discussed is the involvement of the Prairie Provinces Water Board in inter-provincial drainage issues over the years. Chapter 5 presents the DFCC's findings on land cover and agricultural practices in the Basin and how these have changed over the past four decades. This chapter also presents the DFCC's work on determining a relationship between the volume and area of wetlands within the Basin.

Chapter 6 examines the various methods available to assess the effects of drainage and changes in land cover and agricultural practices on hydrology. Relevant published literature is reviewed and, where possible, the methods applied to the Basin. This chapter also outlines the process followed by the DFCC to select a hydrologic model for application to the Basin. Chapter 7 presents the results of the data compilation and model application processes taken by the DFCC. Results of the model calibration and verification process are discussed.

Finally, Chapter 8 provides conclusions based on the data and analyses contained in this report. It recommends actions to mitigate the adverse impacts of land cover and land use changes, and to better understand the effects of such changes.

2 Basin Description

2.1 Physical and Demographic Features

The subject of this report is that portion of the Assiniboine River basin above the confluence of the Qu'Appelle River (Figure 1.1). The Assiniboine River originates out of the Porcupine Hills, northwest of Preeceville in eastern Saskatchewan. A major tributary, the Whitesand River, rises out of the Beaver Hills, northwest of Yorkton and joins the Assiniboine River at the town of Kamsack. From there the River flows into the Lake of the Prairies through which it enters Manitoba to meet the Qu'Appelle River approximately 70 kilometres downstream from Shellmouth Dam. The Basin has a drainage area of 21,000 km^2, of which 79 percent is located in Saskatchewan.

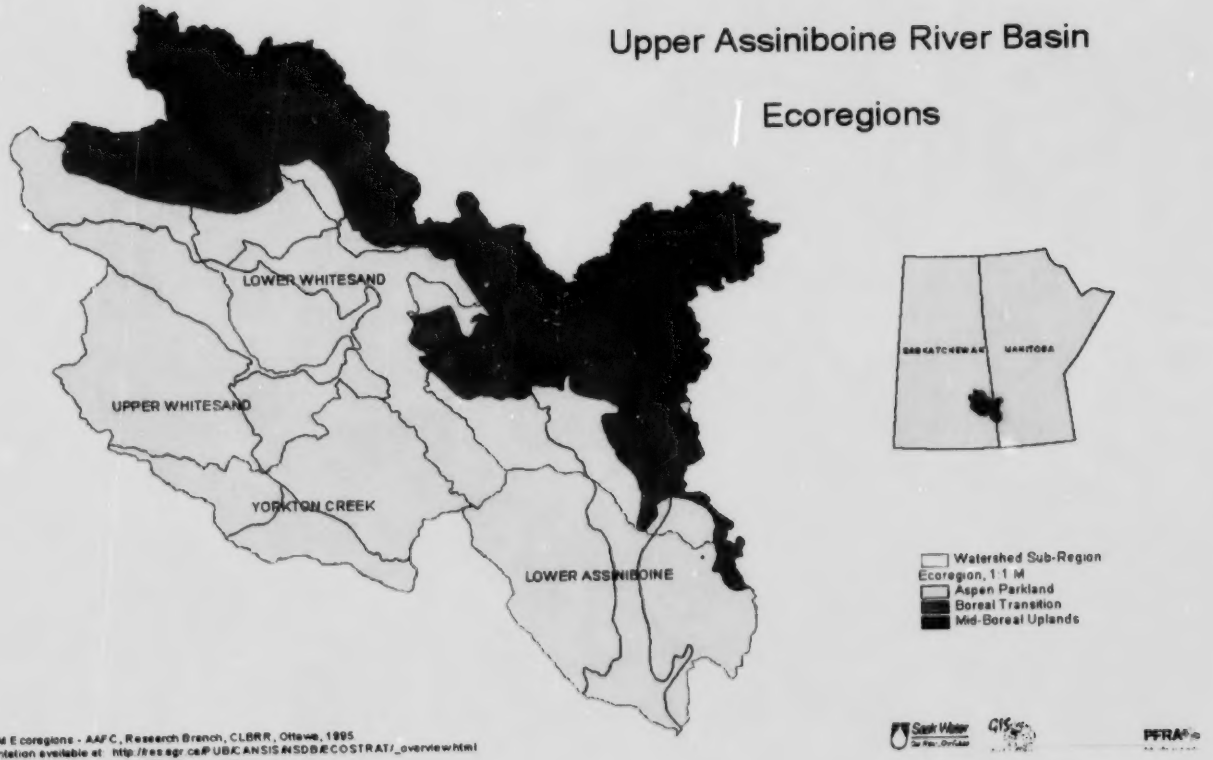
In addition to the Whitesand River, the largest tributary to the Assiniboine River, other major tributaries are the Shell River, Lilian River, and Yorkton Creek, a tributary to the Whitesand River. Several naturally occurring lakes are found in the Basin, most notable of which are Good Spirit Lake, Fishing Lake, and the series of small, interconnected lakes south of Yorkton, which include York, Roussay, Leech, and Crescent lakes, collectively referred to as the Yorkton South Complex.

The northern headwater reaches of the Basin lie within the Mid-Boreal Uplands and Boreal Transition ecoregions, areas characterized by groves of brush, wooded bluffs, steeper flow gradients and reasonably well defined drainage patterns (Figure 2.1). To the south, the lower and largest portion of the Basin falls within the Aspen Parkland Ecoregion, a much flatter terrain with less brush and fewer trees. During the retreat of the most recent glacier, some 10,000 years ago, a condition known as ablation moraine or dead-ice moraine predominated in this area of the Prairie Ecozone resulting in a hummocky landscape, an area pock marked with a myriad of depressions and wetlands.

The Study area has a population of approximately 60,000. The surface and groundwater resources of the Basin are utilized for many purposes. The municipal and domestic use includes the larger centres of Yorkton, Melville, Canora, Kamsack, Russell, Roblin and Preeceville, as well as the many smaller communities and on-farm domestic users. The agricultural needs include more than 100 small scale irrigation projects and a livestock population, mainly cattle, of approximately 200,000. Water is also used for industrial purposes and in-stream, non-consumptive needs, including fish and waterfowl habitat and recreational activities.

Agriculture is the dominant economic activity, with grain farms and livestock operations located throughout the watershed. Examples of industries include meat processing plants, dairies, bakeries, agricultural implement manufacturing, feed mills, and forestry. Two potash mines are located just outside the southern boundary of the Basin.

Figure 2.1
Ecoregions in the Upper Assiniboine River Basin



Recreation is important to the area's economy. The Assiniboine River is used for canoeing and fishing. Good Spirit Lake Provincial Park, the southern edge of Duck Mountain Provincial Park in Saskatchewan, the western edge of Duck Mountain Provincial Forest and Park, and Asessipi Lake Provincial Park in Manitoba are all located within the Basin. There are also several regional parks throughout the Basin. Cottage developments are located primarily at Fishing Lake, Good Spirit Lake, Crystal Lake, and Lake of the Prairies.

2.2 Climate

The climate of the Basin can be thought of in the context of the global hydrologic cycle. In any analysis of the hydrologic cycle the main theme is the concept that water is being constantly circulated in a closed system (the earth) and that the conservation of mass applies (water is neither created nor destroyed). In reviewing Figure 2.2 it is apparent that there are several paths that water can follow. The sun provides the energy to drive the cycle of water evaporating, circulating to the atmosphere where it condenses and then falls as rain or snow. The water then returns to the ocean via surface runoff in streams and rivers and groundwater seepage. There are a number of internal circuits that can occur and these may operate at different speeds (the relatively short time for evaporation from a lake to condensation and return rainfall compared to the much longer time for water to travel via a groundwater route which can extend for several hundred years).

The climate of the area is continental sub-humid. It is characterized by long, cold winters and short warm summers. The mean annual temperature in the Basin is about 1°C. The normal frost-free season extends from 90 to 110 days (102 at Kamsack). The annual growing degree days varies from 1400 near Preeceville to 1600 near Cote.

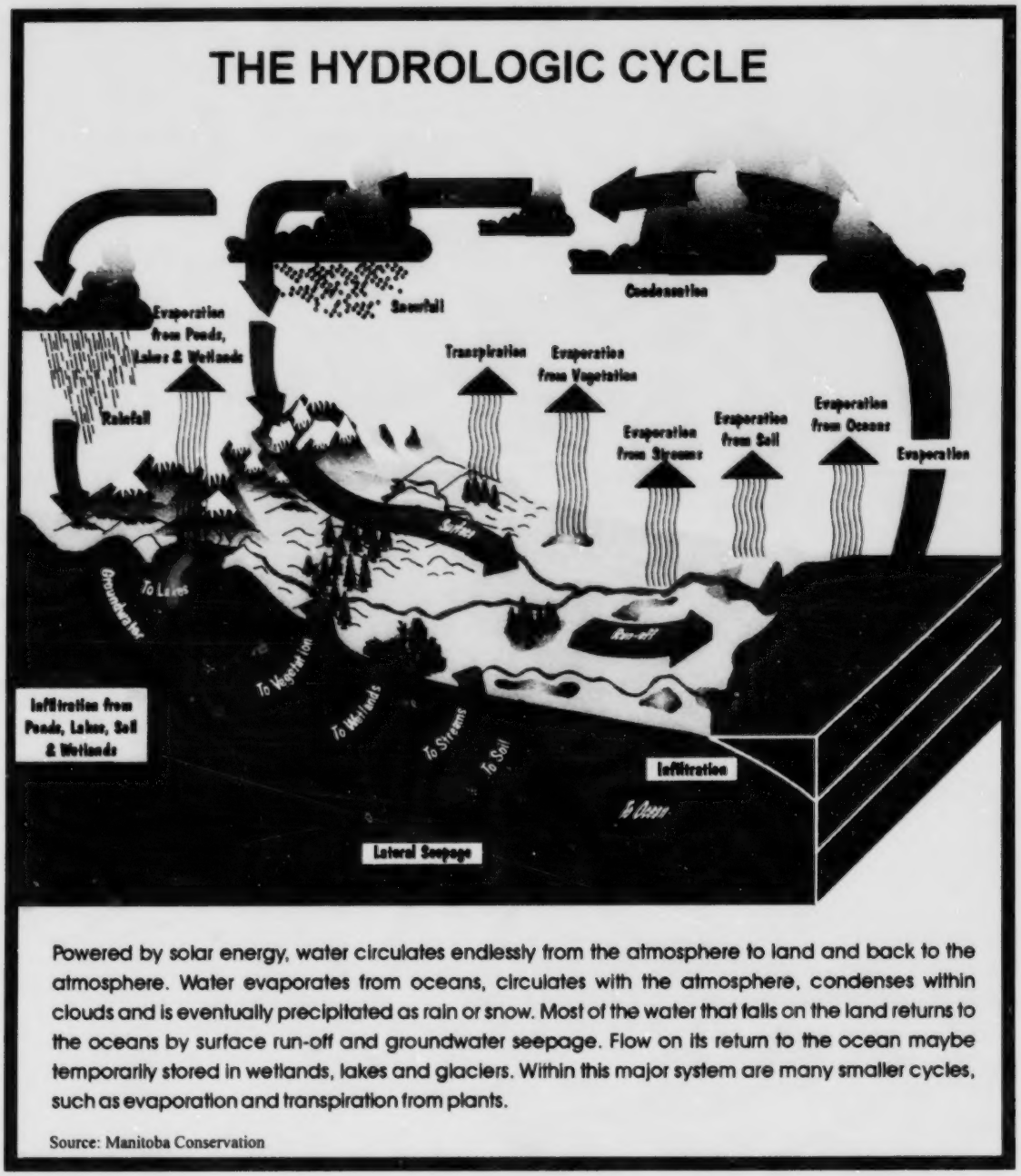
The following is a description of the key climatic elements within the hydrologic cycle as applied to the Basin.

2.2.1 Precipitation

Most of the moisture is provided by air masses originating near the Gulf of Mexico. Convection activity in these air masses during the summer months regularly contributes significant rainfall amounts. The annual precipitation in the Basin averages about 450 mm although it is slightly less in the west and increases to the east. On average about 74 percent of the precipitation occurs as rainfall and the remaining 26 percent is snowfall (see Figure 2.3).

At Yorkton, the average annual precipitation at Yorkton is 440 mm. Figure 2.4 shows the variation in annual precipitation at Yorkton for the years 1961 to 1996. For the period of 1961-1996, rainfall amounts for the Basin have varied annually from 140 mm in 1961 to 550 mm in 1981. The lowest amount of snowfall was in 1981-82 with 42 cm and the maximum snowfall recorded occurred in 1965-66 with 217 cm. These snowfalls are equivalent to 42 mm and 217 mm of water respectively.

Figure 2.2
Hydrologic Cycle Diagram



Powered by solar energy, water circulates endlessly from the atmosphere to land and back to the atmosphere. Water evaporates from oceans, circulates with the atmosphere, condenses within clouds and is eventually precipitated as rain or snow. Most of the water that falls on the land returns to the oceans by surface run-off and groundwater seepage. Flow on its return to the ocean maybe temporarily stored in wetlands, lakes and glaciers. Within this major system are many smaller cycles, such as evaporation and transpiration from plants.

Source: Manitoba Conservation

Figure 2.3
Monthly Precipitation at Yorkton

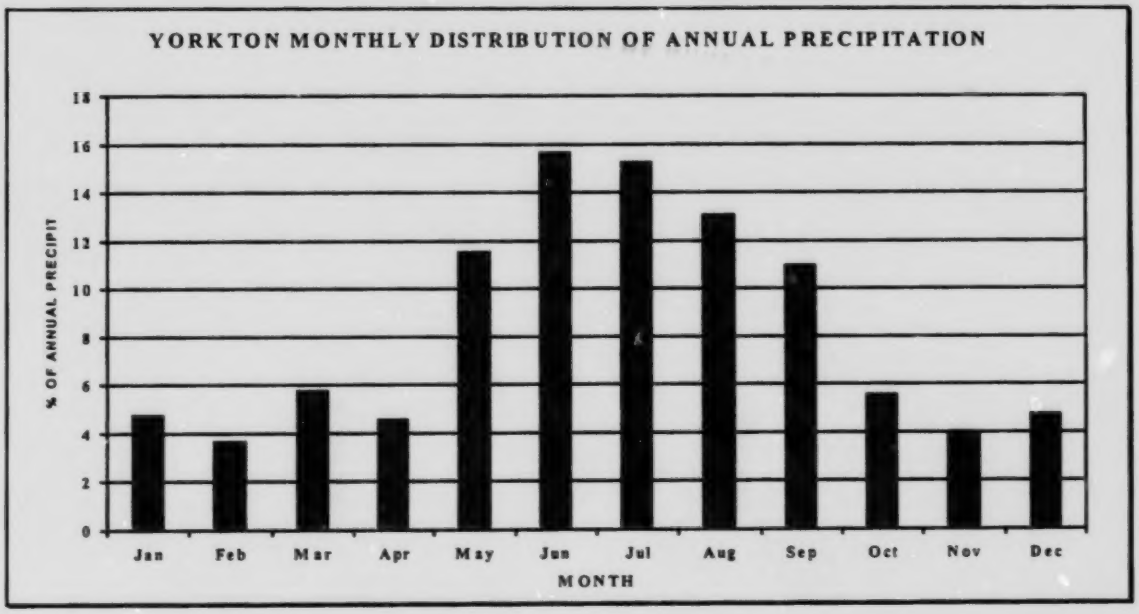


Figure 2.4
Total Annual Precipitation at Yorkton

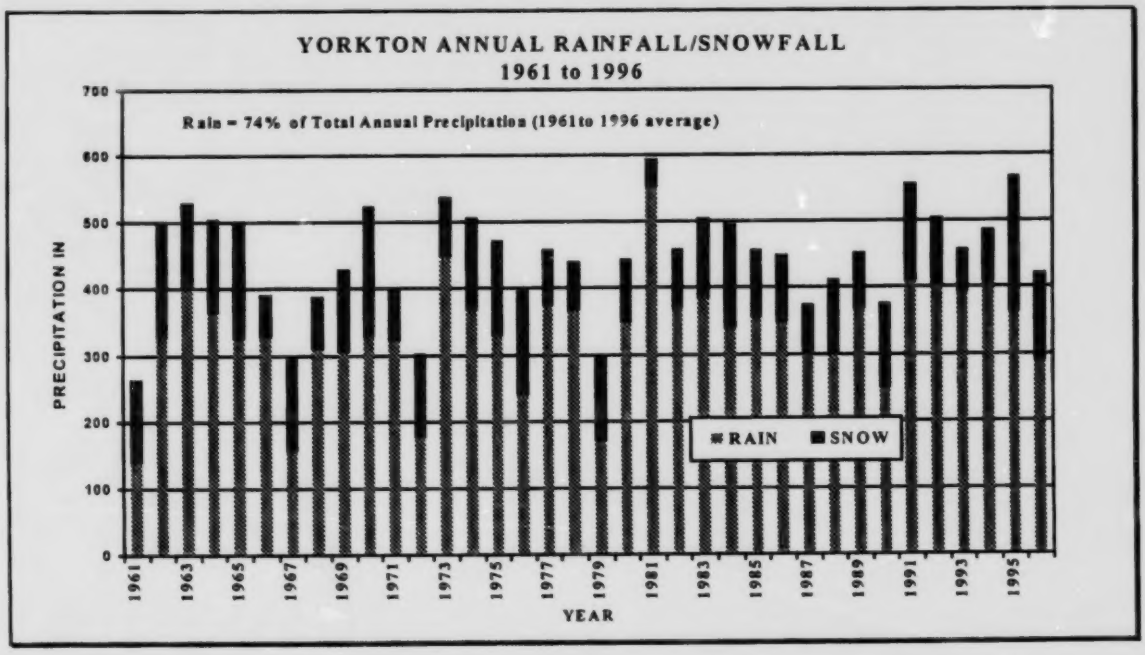


Table 2.1 presents average annual temperature, precipitation, and growing degree-days (GDD) data for selected locations in and around the Basin.

Table 2.1 - Average Climate Data (1961-1990)

Sample Climate Statistics (1961-1990) - Upper Assiniboine Principal Stations (Hourly Data)					
Name	Mean Annual Temperature (C)	Rain Annual (mm)	Snow Annual (cm)	Total Precipitation Annual (mm)	GDD* Annual (C)
In-Basin					
Yorkton A	1.4	318.1	128.7	435.8	1577
Russell	1.1	343.7	139.0	484.4	1542
Cote #	1.3	341.0	111.2	452.2	1599
Preeceville #	0.0	320.9	141.4	461.9	1397
Kuroki	0.6	319.3	160.1	479.4	1472
Langenburg #	1.1	330.9	110.4	446.1	1521
Near Basin					
Hudson Bay A #	0.8	332.0	174.4	456.0	1437
Wynyard	1.6	294.5	129.0	406.3	1563
Broadview	1.8	294.7	126.8	398.9	1553
Dauphin A	1.7	366.3	137.9	491.9	1631
Birtle	1.3	358.5	125.9	484.5	1581
Swan River	1.4	358.9	139.2	498.2	1590
Pelly	-0.2	344.7	162.0	506.1	1267
Porcupine Plain#	0.4	326.9	123.0	451.0	1556
Kelliher	1.3	304.0	131.0	435.0	1502

* Growing Degree Days
# less than 30 years of data

2.2.2 Evaporation

The mean annual potential evaporation from a water body for the Yorkton area is 850 mm. The value for an extreme dry year is 1090 mm. During a very hot day about 10 mm can evaporate. The term 'Net Evaporation' is used by hydrologists to describe the net effect of evaporation from the surface of a water body minus precipitation onto the water body. For the Yorkton area, the 850 mm average annual evaporation minus 440 mm average annual precipitation yields 410 mm average annual net evaporation.

Evaporation during the winter, a process known as sublimation, occurs when snow or ice vaporizes, that is, it changes directly from the solid phase to the vapour phase. In the Basin, sublimation typically averages 15 to 20 percent of the annual snowfall.

2.2.3 Transpiration

Most of the water absorbed by the roots of plants is discharged to the atmosphere as vapour as part of the photosynthesis process. The depth of the roots affects the ability of plants to transpire water to the atmosphere. As neither evaporation nor transpiration can be easily or directly measured, they are usually combined. Evapotranspiration is the term used for the combination of evaporation from the soil surface and transpiration. In the Canadian Prairies, annual evapotranspiration can be as high as 80 to 90 percent of the annual precipitation.

2.3 Water Resources

The water resources of the Basin are a function of the climate and topography, in conjunction with the Basin soils and vegetation. This section continues the discussion of the hydrologic cycle by looking at the groundwater, wetland, and surface water resources of the Basin.

2.3.1 Groundwater

Some precipitation soaks into the ground through a process termed infiltration and that portion of the infiltrated water which reaches the water table is termed groundwater. If the water table is close to the ground surface, plant roots may extend into the water table and some of the groundwater may be transpired. Under the influence of gravity, groundwater may move either vertically to deeper groundwater formations (aquifers), or laterally to re-emerge at the ground surface as springs or seeps. Contributions to groundwater (recharge) may on average be in the order of 5 percent of annual precipitation for watersheds underlain by glacial till in the Canadian Prairies. On closer examination, recharge is episodic, occurring only after snowmelt or large rainfall events, and generally over small areas (recharge areas). For the Basin this may mean groundwater contributions in the order of zero to 30 mm per year.

2.3.2 Wetlands

Prairie wetlands serve a number of functions in the hydrologic cycle (NHRC, 1994). Wetlands usually act as large sponges or dampers within a watershed, temporarily storing runoff and releasing excess water in a slow, controlled manner. This natural process reduces the magnitude of downstream flooding in most years.

Wetlands also function as areas of groundwater recharge and discharge. They act as an interface between surface water and groundwater. Water from wetlands percolates into the groundwater system and thus recharges supplies. This process also results in the stabilization of groundwater tables. These phenomena occur at both regional and local scales and benefit agricultural and

domestic groundwater users. Wetlands also can provide surface storage of excess groundwater. In other words the same wetland could both recharge groundwater supplies and receive and store groundwater discharges depending on the relative groundwater and wetland elevations.

In addition to their role in the hydrologic cycle, wetlands assist in controlling soil erosion. Wetland complexes provide temporary storage of excess runoff within the watershed, which reduces downstream flows and accompanying erosion. The vegetation within wetlands and other riparian habitats also functions as shoreline protection and provides additional erosion protection. Wetlands act as traps by reducing the amounts of sediments released downstream. Sediments transported in surface runoff are deposited within the wetlands because of the decreased water velocities on entering the larger flow area.

2.3.3 Surface Runoff

Surface runoff is the water that is transported along the surface of the earth, as opposed to within the earth, and reaches a stream or water body soon after the occurrence of the rainfall or snowmelt event. In the Canadian Prairies, surface runoff is usually the residual after evapotranspiration and infiltration losses have occurred.

Unit runoff, or total runoff volume per unit of drainage area, is expressed in units of cubic decametres per square kilometre (dam^3/km^2) which is equivalent to millimetres of runoff depth over the drainage area. This facilitates ready comparison with precipitation and evapotranspiration rates. The average value of annual unit runoff varies between 10 mm at Melville to 100 mm in the Duck Mountain region (Bell and Martin, 1994). Over the period 1941 to 1995, annual unit runoff over the entire Basin has ranged from 8 mm in 1961 to 169 mm in 1995, and has averaged 46 mm.

Many factors affect how much precipitation becomes surface runoff. These include climatic factors such as precipitation type (snow or rain), precipitation intensity and duration. Other factors relate to the watershed such as antecedent conditions (fall soil moisture and fall storage available in wetlands and surface depressions), the slope of the land (mild or steep), vegetation cover on the soil (trees vs. pasture), soil type (clay vs. sand) and condition (frozen vs. thawed).

Winter snowfall plays a large role in the hydrology of the Basin. During the winter months precipitation accumulates as snow and only the major streams continue to flow. Examination of Figures 2.5 and 2.6 show most of the flow occurs during April, May and June. The smaller the size of the watershed, the more compressed is the spring runoff event that occurs. It is important to note that even though most of the precipitation is from rainfall, most of the runoff is the result of the melting of the accumulated winter snowfall. The magnitude of spring runoff depends on factors such as the soil moisture at freeze up the previous fall, winter and early spring precipitation totals, the rate of spring melt, and the relative timing of runoff from upstream tributaries.

Figure 2.5
Assiniboine River at Kamsack

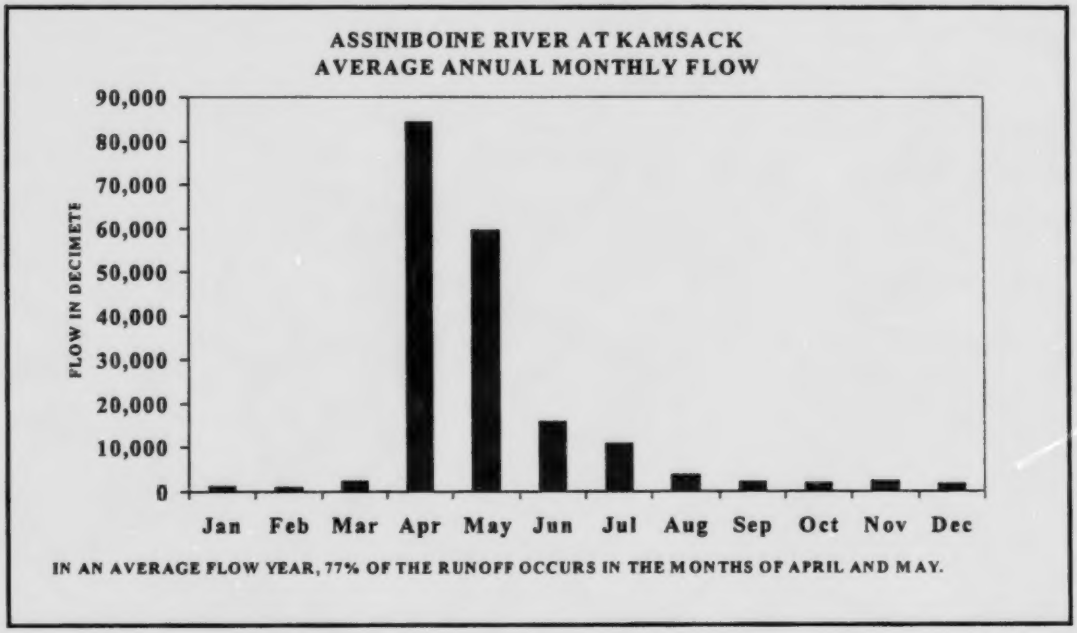
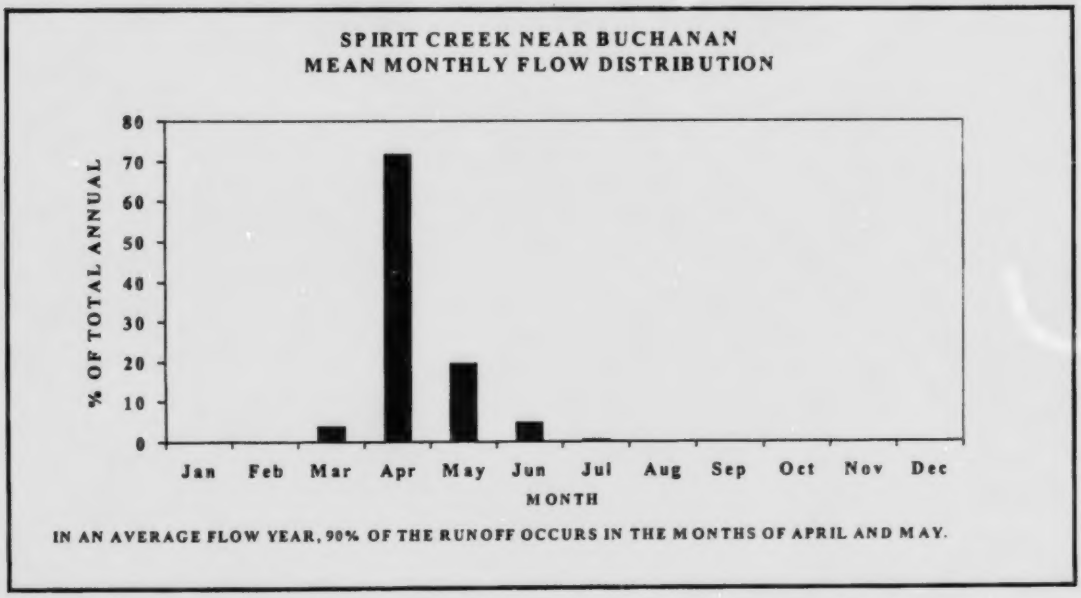


Figure 2.6
Spirit Creek near Buchanan



Flow records from the hydrometric station on the Assiniboine River near Russell span the period from 1913 to 1999 (Figure 2.7). This figure provides a good indication of the year to year variability of flows within the Basin. In 1922 the maximum annual flow volume was recorded at 1,820,000 cubic decameters (dam^3), as compared to the minimum annual volume of 60,100 dam^3 recorded in 1961. The second highest annual flow volume at the Russell station was 1,470,000 dam^3 in 1913, while the more recent 1995 annual flow of 1,300,000 dam^3 was the fourth highest on record.

Similarly, Figure 2.8 shows the annual peak flows for the same period for the Assiniboine River near Russell. The largest peak flow was in 1995 at 708 m^3/s. The 1922 peak flow was the second largest, at 550 m^3/s. The third largest peak occurred in 1923 at 411 m^3/s. In both figures, the effect of Shellmouth Dam and Lake of the Prairies is removed starting in 1969 when the dam was completed and the lake began to fill.

2.4 Water Resource Projects

There are five major water storage projects and lakes in the Basin. Each is briefly described, in upstream to downstream sequence.

2.4.1 Fishing Lake

Fishing Lake is a large natural lake located in the far northwestern portion of the Basin. This lake has a surface area of 3,680 ha and a volume of approximately 259,000 dam^3 at its natural overflow elevation of 529.74 m. Until 1997, there had been no documented instances of Fishing Lake ever reaching its natural overflow level. When this did occur in 1997, reaching a peak elevation of 529.9 m, numerous properties and developments located below the elevation of 529.74 m sustained substantial flood damage.

In 1997, the Fishing Lake Watershed Association was established and put forward a proposal to lower lake levels by lowering the natural spill elevation of Fishing Lake by 0.90 m with an outlet control structure and approximately 7 km of ditching to the Whitesand River (Sask Water, 1997). This would provide flood protection to property around the lake. Some adverse downstream effects, due to lowering the spill elevation of Fishing Lake and increasing the release of water, were been identified. The Watershed Association is now revising its proposal.

2.4.2 Theodore Reservoir

The Theodore Reservoir is situated on the Whitesand River approximately six kilometres east and three kilometres north from the Town of Theodore. The project was constructed by PFRA in 1964 but is now owned by Sask Water. At its Full Supply Level of 497.74 m, the reservoir floods 287 ha and stores 14,300 dam^3.

Figure 2.7
Annual Runoff Volumes Assiniboine River near Russell 1913 to 1999

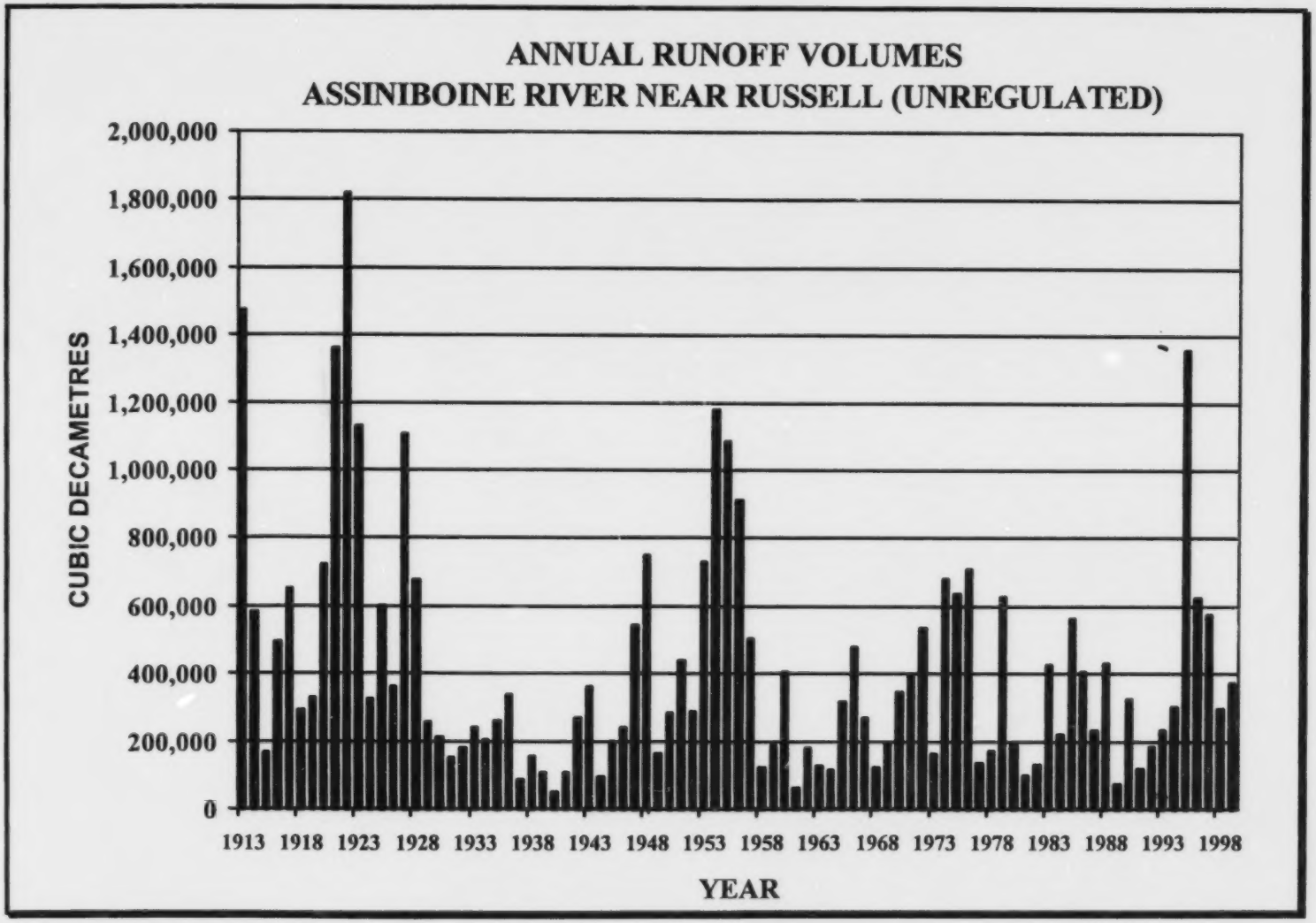
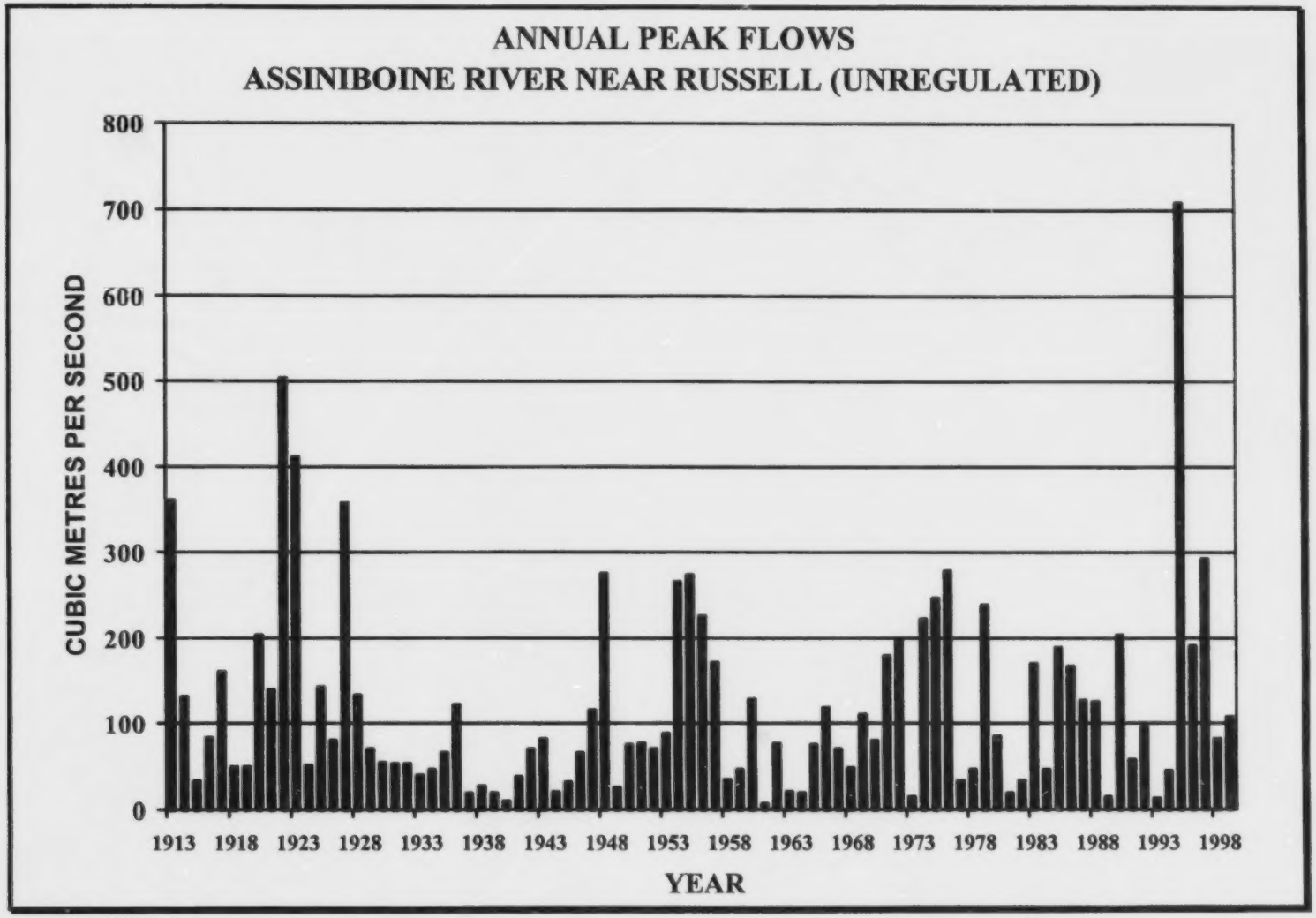


Figure 2.8
Annual Peak Flows Assiniboine River near Russell 1913 to 1999



The main purpose of this reservoir is for water supply storage. This site was selected over several others because of the potential downstream agricultural benefits, and because it would sustain the least potential damage from the reservoir surcharging during a flood event. The reservoir was proposed to provide 4,500 dam^3 of water annually for domestic and livestock purposes downstream, and to augment water supply for the Town of Canora. The reservoir was essential to the Town of Canora during times of drought.

Canora has recently developed a new domestic water supply. This new source is an aquifer located to north of the Town and will eliminate the Town's reliance on water from the Whitesand River and the Theodore Reservoir.

2.4.3 Yorkton South Complex

The Yorkton South project is a complex of 10 basins located south and west of Yorkton (see Figure 2.9). Essentially it is a flood storage complex with agriculture, recreation, wildlife and waterfowl benefits. Crescent Creek flows from the south into the system. Willow Brook, to the west, is diverted into Yorkton South.

There has been a long and often controversial history to the development of this complex. In 1899, following an extensive drought, the Willow Brook Diversion dam was built by the North West Territorial Government. This project also included a diversion to York Lake, a recreation lake for the City of Yorkton. A subsequent series of high runoff years resulted in too much water in the system. For several decades controversy followed when there was too much or too little water in the system, depending if it was a wet or dry cycle. In the mid-1970s, the Yorkton Creek Ad Hoc Committee was formed to help investigate and resolve issues within the watershed. In 1977 the Yorkton Creek Watershed Association was established with representation from a broad spectrum of interests in the development and management of water in the area south and west of Yorkton. Construction of the various channels, dykes and controls ensued over the late 1970s and early 1980s by Ducks Unlimited and the Watershed Association.

The system has worked very well over the past twenty years. During the flood of 1995 there were no operational problems and very few flood concerns expressed by the local landowners on the complex. The formation of a Watershed Association was successful in this situation.

Figure 2.9
Yorkton South Complex

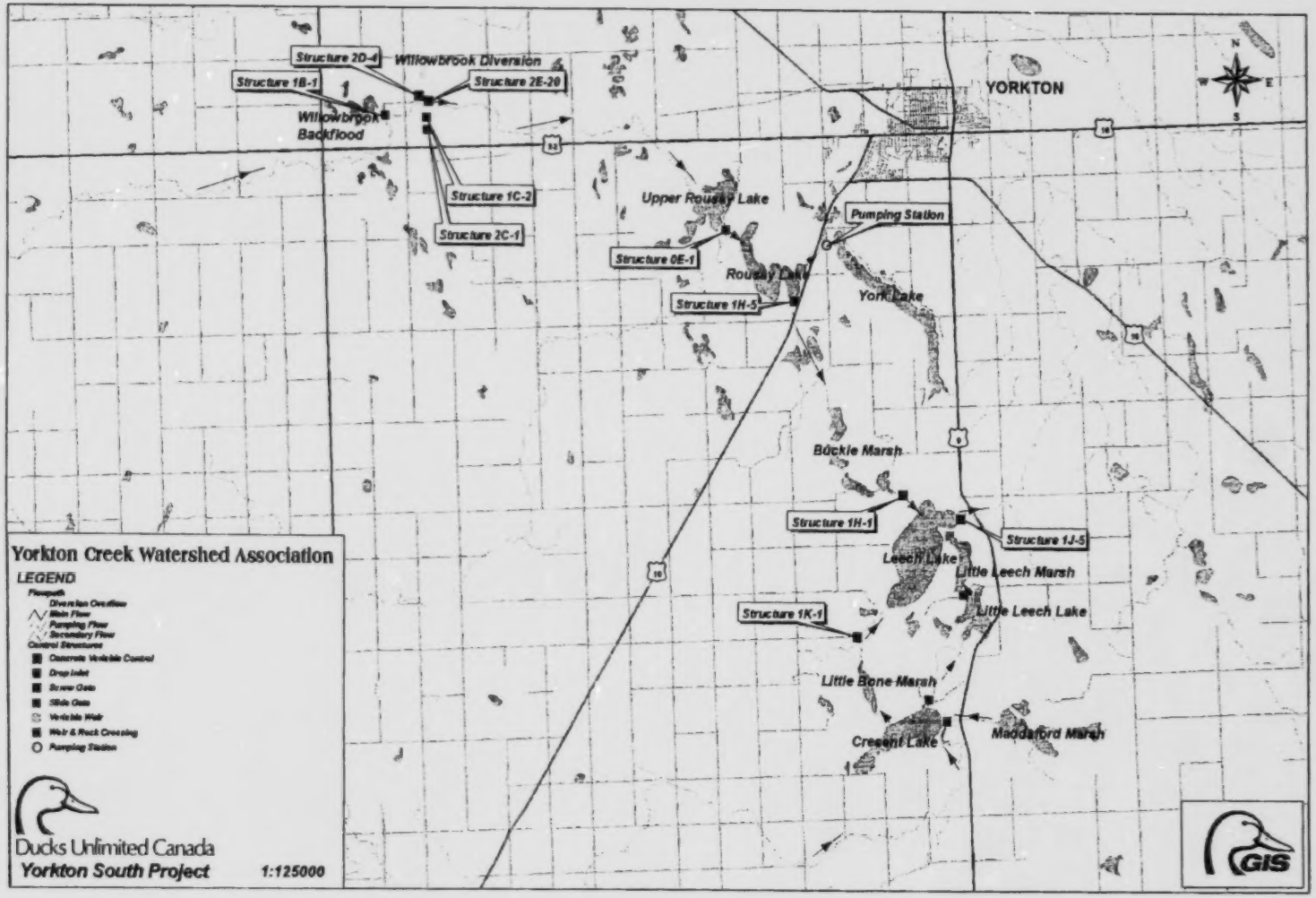


Table 2.2 lists the surface areas and water storage capacities at normal operating levels (N.O.L.) of each of the water bodies that make up the Complex.

Table 2.2 - Yorkton South Complex

Segment	Flooded Area at N.O.L. 0(ha)	Volume at N.O.L (dam^3)
Upper Rousay Lake	378	1961
Lower Rousay Lake	421	3852
York Lake	333	5387
Buckle Project	296	1113
Leech Lake	749	8900
Leech Marsh	204	1468
Little Leech Lake	402	2023
Little Bone Lake	104	979
Crescent Lake	288	3596
Maddaford Marsh	395	2460
Total	3570	31739

N.O.L. Normal Operating Level

2.4.4 Good Spirit Lake

Good Spirit Lake is a natural lake located approximately 20 kilometres southwest of Canora. The lake covers about 4,560 ha at its spillway elevation of 485.00 m. The target elevation for June 1 each year is 484.8 m, at which point the lake contains approximately 207,000 dam^3. The lake is quite shallow (maximum depth is about 7 metres) with a flat bottom and a regular shoreline. The lake is located within a sand formation and has extensive beaches and dunes located on the south and east shores. The main inflow is from Spirit Creek, a watershed with a predominantly agricultural land use. The water quality is quite good for a basin located in the southern part of the Province. It is used extensively for recreation. Good Spirit Lake Provincial Park is located on the south end and there are about 550 cottages located within a number of developments around the lake.

The basin is essentially a semi-closed basin. It has spilled only during high water cycles such as in the mid 1950s, mid 1970s, mid 1980s and more recently in 1995. The natural outlet of the lake is located within the dune formations at the south east end of the lake. During high runoff years prior to 1988, the dunes (which act as a dam) were washed away which resulted in uncontrolled water levels on the lake and unregulated releases downstream to the Whitesand River. Once 'normal' conditions returned to the lake, the dunes were re-formed naturally and again acted as a dam.

Historically, there have been various attempts made, during high water cycles, to install a control structure on the outlet of Good Spirit Lake. These efforts failed largely because of costs associated with the outlet development. In 1985, interest was again renewed. This time there was new legislation available, *The Watershed Associations Act*, through which funding could be accessed. Two RMs and several Conservation and Development Area Authorities make up the Board of the Good Spirit Lake Watershed Association. A number of agencies including SERM, Sask Water and Ducks Unlimited have advisory status to the Association Board. Ducks Unlimited was interested in developing the adjacent Heritage Marsh, called Horseshoe Lake, concurrently. In 1988, a control structure and eight kilometres of downstream channelization improvements were constructed.

2.4.5 Shellmouth Dam and Lake of the Prairies

The Shellmouth Dam and its associated reservoir, named Lake of the Prairies, was developed as a multi-purpose facility on the Assiniboine River in Manitoba. The project was developed primarily to provide flood control benefits to Brandon and Winnipeg. Other uses of the Lake include provision of municipal water supplies for the cities of Brandon and Portage la Prairie, colling water for thermal-electric generation, irrigation, stockwatering, sewage effluent dilution, and enhancement of recreation and fisheries both in the Lake and along the Assiniboine River between the Lake and Winnipeg.

The Shellmouth Dam was designed and built by PFRA and was completed in 1970. An aerial photo of the dam under construction is shown in Figure 2.10. Manitoba assumed responsibility for ownership and operation of the project in 1975. The dam, located about 20 km northwest of Russell, has a maximum height of 22 m, a crest length of 1,270 m, a 4.6 m diameter reinforced concrete conduit with a chute spillway at its outlet for making controlled releases from the reservoir, and an ungated concrete chute spillway designed to pass the thousand year flood. The reservoir created by the dam extends approximately 60 km upstream, and is capable of storing 370,000 dam^3 at the normal summer operating level of 427.5 m and 477,000 dam^3 of water at the spillway crest elevation of 429.31 m.

Since some of the reservoir functions are conflicting and some are compatible, the operation of the reservoir must be carried out in such as manner as to optimize the benefits and minimize conflicts to all those affected. Generalized operating guidelines have been developed to ensure that the reservoir can provide reasonable levels of both flood protection and water supply. Within the current operating regime developed by Manitoba Conservation, some discretionary variation is possible to meet the various interests at specific times. Below is a summary of the generalized operating guidelines for Lake of the Prairies.

1. The reservoir is gradually lowered over the fall and winter period to provide flood storage capacity for the spring runoff, which usually beings around the end of March. The winter drawdown target level is somewhat variable, dependent upon the spring inflow forecast. The original operating rule was to draw the reservoir down to a fixed winter target level

of about 423.98 M However, with improved probabilistic forecasting techniques the reservoir may now be lowered well below this point to increase flood storage capacity, or held well above this point to increase the likelihood that the available runoff will provide sufficient storage for water supply and recreational use during the summer period.

2. During spring runoff, primary consideration is to control reservoir outflows to minimize downstream flooding. Excess inflows are stored in the reservoir until the water level nears the spillway crest elevation of 429.32 m. If inflow forecasts indicate that the spillway will be used, outflows will be increased so as to minimize the eventual peak outflow. The intent is to minimize overbank flooding along the river below the dam and during flood periods to keep outflows to a value no greater than what the river flow would have been without the dam in place. At present, an attempt is made to maintain outflows to a maximum of about 45.3 m^3/s to prevent localized flooding and facilitate land drainage.

3. After spring runoff, reservoir levels are gradually lowered by conduit releases to a summer target level of about 427.5 m to optimize recreational and fishery conditions. The reservoir level may be held as much as 0.5 m higher to reduce the chances of water supply shortages when summer drought conditions are anticipated.

4. In the event of summer rainfall floods, the available reservoir storage above the target summer level of 427.48 m is used to reduce downstream flow rates and minimize flooding. Outflows are increased if the level exceeds 428.25 m in order to reduce flooding of recreation facilities and to minimize the chance of using the spillway.

5. During normal summer operation, the primary consideration is to make reservoir releases to meet water allocation commitments to downstream licensed users and domestic users, and to meet instream flow needs. Reservoir release rates are dependent upon the prevailing inflow rates, long-term inflow forecasts, and downstream tributary flows and water demands. Reservoir release rates are varied throughout the year to meet a minimum target instream flow for 0.71 m^3/s immediately below the dam and 5.67 m^3/s at Headingley. Consideration must also be given to other factors such as travel time of Shellmouth Dam releases and maintaining an adequate reservoir level for recreational and fishery purposes.

Figure 2.10
Aerial View of Shellmouth Dam

SHELLMOUTH DAM
Photo taken from air showing construction to July 2, 1969.
Regina Ref. 29505

3 Issues

3.1 Major Floods

3.1.1 The 1995 Flood

The spring 1995 saw the largest flood event in the Basin since 1922. The 1995 flood became the driving force leading to the issues identified by the public for examination during the course of the Study. At some locations peak flows in 1995 were the highest recorded over the history of the streamflow station. The climatic conditions which led to the 1995 flood were as follows:

- Above average rainfall over the summer and fall of 1994 produced wet antecedent conditions over much of the Basin. The wet conditions filled many of the wetlands and saturated the ground before freeze-up.

- There were high snowfall accumulations over the winter of 1994-1995. Total winter precipitation was the third highest on record since 1948. Much of the accumulation occurred late in the winter and was therefore more effective in generating runoff. Early winter snowfall is subject to higher evaporation and sublimation losses. While winter precipitation was near the long term normal for November 1994 through January 1995, the February snowfall was about 200 percent above normal (i.e., triple the normal February snowfall). A series of storms passed through the Basin during March and early April. Snowfall in March ranged from 200 percent to 300 percent above normal (i.e., three to four times the normal snowfall).

- Cold temperatures persisted through the first half of April, allowing further accumulation of snow. During the first two weeks of April, precipitation was 150 percent to 200 percent above normal.

- A significant melt period in mid-March ripened the snowpack and caused ponding of up to one metre on top of ice cover in sloughs and streams. Cold temperatures returned and persisted until mid-April. With the colder temperatures, this ponded water froze. When runoff resumed in earnest in April, the heavy ice cover in stream channels formed ice jams and exacerbated flood conditions.

- Over the Easter weekend of April 14 to 16, 20 to 30 mm of rainfall occurred. This caused an immediate and rapid melting of the snowpack over much of the Basin. The last half of April saw a continued high melt rate with maximum daily temperatures recorded at Yorkton averaging 8°C from April 19 to 24.

The rapid onset of melting across the Basin resulted in the near coincidence of peak flows on both the Whitesand and Assiniboine rivers at Kamsack. Normally, melting begins in the south of the Basin and proceeds northward and eastward so that the peak flow of the Whitesand River

precedes the peak of the Assiniboine River above Kamsack. The peak flow of 484 m^3/s at Kamsack occurred on April 24. The Shell River and local tributaries such as Stony Creek near Kamsack also reached their peak flows on April 24. The resulting peak inflow to Shellmouth Dam of 708 m^3/s occurred on April 25.

Peak flows at a number of locations in the Basin have been analysed to estimate the probability of recurrence, or conversely the return period. The results of that analysis are summarized in Table 3.1.

Table 3.1 - Estimated Probabilities of Recurrence - 1995 Peak Flows

Location	Station Number	1995 Peak Flow (m^3/s)	Probability of Recurrence	Return Period	Reference for Peak Flow Frequency Analysis
Yorkton Cr. nr Ebenezer	05MB001	53.7	3.3%	1:30	Fahlman and Banga, 1991
Whitesand R nr Canora	05MB003	247	0.80%	1:125	Banga, 1995
Assiniboine R at Sturgis	05MC001	111	1.4%	1:70	Oegema, 1997
Stony Creek nr Stenen	05MC002	34.0	1.1%	1:90	Johnson, 1997
Assiniboine R at Kamsack	05MD004	484	1.0%	1:100	Banga, 1995
Assiniboine R nr Russell (regulated)	05ME001	354	1.1%	1:90	Manitoba Conservation, 1999
Shellmouth Dam Inflows	n/a	708	1.1%	1:90	Manitoba Conservation, 1999

Table 3.1 shows that at a number of locations, peak flows were in the order of the 1:100 year flood. Inflows to Lake of the Prairies (Shellmouth Dam) are not measured directly but are calculated based on recorded water levels and known outflows. The estimated peak inflow was computed at 708 m^3/s. The local inflow between Kamsack and Shellmouth Dam was estimated to be 160 m^3/s, a 33 percent increase over the peak flow at Kamsack. The peak flow on the Shell River, which enters Lake of the Prairies above Shellmouth Dam, was recorded at 65 m^3/s.

Management of the storage reservoirs and major lakes in the Basin had varying effects on flows. As snowfall accumulations grew over the late winter, Manitoba Water Resources Branch managed to draw down Lake of the Prairies to elevation 424.9 m by April 10. The Lake had insufficient capacity to prevent downstream flooding due to the enormous volume of runoff and water levels exceeded the concrete overflow spillway crest elevation of 429.31 m from April 26 to May 25. Nevertheless, operation of the project reduced the peak outflow on May 3 to 354 m^3/s, half of what would have been experienced without the Lake. This reduced water levels immediately below the Dam by 1.5 m. Along the Assiniboine River water levels were reduced in the range of 0.6 to 0.9 m. If it had been possible to foresee the magnitude of the spring snowmelt runoff, Lake of the Prairies could have been drawn down further to provide additional flood storage. However, calculations by Manitoba Water Resources Branch have shown that even if

the Lake had been at record low levels prior to runoff, peak water levels on the Assiniboine River below the Dam would have been further reduced by no more than 0.3 m.

Fishing Lake levels increased over the course of the runoff but levels did not reach the natural overflow level and no water spilled out of Fishing Lake into the Whitesand River. Theodore Reservoir went into the winter nearly full. During the flood of 1995, the reservoir had very little impact on peak flow rates in the Whitesand River.

The Yorkton South Complex operated as designed under flood conditions. Most of the individual projects surcharged by up to one metre over their Normal Operating Levels during the runoff. Flows were diverted from Willow Brook into the Complex, thus assisting to some degree to alleviate flood conditions along the Whitesand River. The effect of the Complex as a whole was to substantially attenuate flows on Yorkton Creek, and to some degree on the Whitesand and lower Assiniboine rivers. As shown in Table 3.1, the estimated return period of the Yorkton Creek peak flow was 1:30 compared to about 1:100 at other locations in the Basin.

Good Spirit Lake was at elevation 484.06 m in the fall of 1994. The lake reached a peak elevation of 485.09 m on May 12, 1995. Outflow from the lake was initiated on April 28 and continued until July 2 when the lake was at elevation 484.67 m. Spill occurs when levels are above 485.00 m. In 1995, this was from May 2 to May 31. No damages occurred to cabins around the lake, although cottagers were concerned that levels might exceed 485.10 m. Operations of the control structure reduced peak outflows slightly from what would have otherwise occurred but did not have a significant effect on flows in the Whitesand River.

Many downstream residents contend that upstream drainage of thousands of wetlands has fundamentally changed the nature of the runoff response in the Basin. Observations of the 1995 flood from the air (see Figure 3.1) clearly showed that during the period of high streamflow, high levels in the receiving streams prevented or reduced flow in many drainage ditches.

Field observations in the fall of 1994 indicated that the high precipitation had filled many of the natural wetlands and that the soil moisture levels were high. These factors reduced the storage available to retain snowmelt runoff in the spring of 1995. The reduced natural wetland storage was then very small relative to the large volume of runoff that occurred in 1995.

3.1.2 The 1922 Flood

The 1995 flood was the largest runoff event to be experienced in the Basin since 1922, when an approximately 1:50 peak flow occurred. Figure 3.2 shows the 1922 and 1995 flood hydrographs at Shellmouth Dam. There are striking differences between the hydrographs for the two years. The peak discharge in 1995 was greater with the rising and falling limb of the hydrograph being much steeper. In 1922, total volume was approximately 45 percent greater than in 1995, with a much flatter flood hydrograph. The area under each hydrograph represents the total discharge volume.

Figure 3.1
Lake of the Prairies Inflows, 1922 and 1995 Discharge Hydrograph Comparison

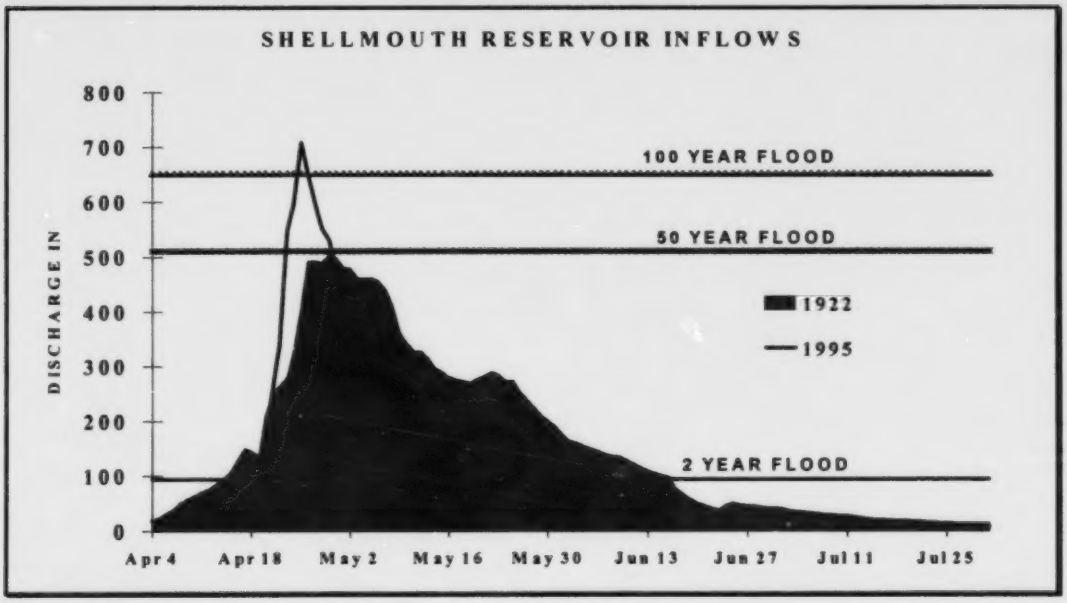


Figure 3.2
Aerial view of Typical Conditions during 1995 Flood

Streamflow records on the Assiniboine River extend back to 1913, but the 1922 flood was reported at the time by long-time residents as the worst since 1882, and was followed other large floods in 1884 and 1902. The spring runoff in 1922 produced the highest runoff volumes on record in the Basin. The 1922 flood was particularly damaging because of its unusually long duration. For example, the Assiniboine River at Russell exceeded the typical bankfull capacity of 85 m^3/s from April 13 to June 16, inundated thousands of acres of arable land, and caused much damage to buildings, bridges and highways. A brief review of the causes and effects of the 1922 flood is documented in a March 1923 report prepared by C. H. Attwood of the Water Power Branch, Canada Department of the Interior, entitled " Report on the Assiniboine River Floods, April and May 1922".

Attwood reports that "The Assiniboine flood of 1922 was due to climatic conditions in the upper watershed, principally in Saskatchewan, in the fall of 1921 and the spring of 1922." Precipitation was 205 percent above normal in September, 70 percent above normal in October and 60 percent above normal in November, 1921. The fall rains thoroughly saturated the soil and filled the lakes and sloughs just prior to freeze-up, which occurred about November 6. Winter precipitation was only a little above average, and temperatures during the melt period were normal. The spring break-up occurred during the first week of April, and was followed by two heavy snowstorms on April 9 and 10. These storms were followed by heavy rains and high temperatures. The land, still saturated from the rains the previous fall and the spring thaw, could absorb practically none of this heavy precipitation, and the water quickly found its way into the main channel of the Assiniboine River and its tributaries, causing excessive high water and flooding. The peak flow of 504 m^3/s at Russell occurred on April 29. Heavy rains on the upper watershed during the first half of May were responsible to a large extent for the continued long duration of the flooding.

3.2 Wetland Drainage

Property owners believe that drainage of wetlands located upstream in the watershed leads to increased flooding and erosion, and to diminished water quality.

The Basin is characterized by numerous shallow potholes or sloughs that retain the spring runoff for a limited time period. Because many wetlands are either temporary or semi-permanent, they are perceived by the agricultural community as unproductive for both wildlife and agriculture. They are felt to dry out too early to benefit waterfowl and are of little use for agriculture. Agricultural producers feel that wetlands hinder agricultural operations and they desire to develop these areas for annual crop production. Producers also expressed concern about the potential for an overriding focus on environmental values that may affect the ability of the landowner to develop land. A high proportion of these wetlands may be easily drained because of relatively flat topography and proximity to an outlet.

In today's agricultural world several factors are conducive to wetland drainage:

- Modern earth moving equipment is readily available to farmers making it relatively easy for them to drain wetlands.

- Wetlands are a nuisance to annual crop production because their presence makes operation of large farm equipment less efficient increases farm inputs. It is more economical and efficient to crop in regular straight lines.
- Larger farms are required today in order to be economically viable because of diminishing returns. Large farms tend to be focused on cereal production rather than smaller mixed farms of the past. As land changes hands from smaller operations to modern large producers the first steps often taken are to clear and drain in order to make land more efficient.
- The short growing season coupled with the large land base necessitates being on the land as soon as possible in the spring. Drainage helps to accomplish this objective.
- Moisture is not normally a limiting factor for crop production in the Basin as opposed to other areas of the prairies. In fact the opposite exists, excess spring moisture often delays seeding.
- The cost of land and the need to be efficient encourages producers to first maximize cultivated acres within their present holdings before acquiring additional lands.

Drainage raises several issues. Downstream landowners are forced to undertake either their own drainage works and channel improvements to pass the surplus water along, or, where such works are not possible, practicable or desirable, the extra water may cause flooding of farmland adjacent to the watercourse. This flooding can remove land from production temporarily, seasonally or even permanently. Landowners downstream of drainage developments feel that they suffer from the consequences of land drainage while the upstream landowners derive the benefits from the drainage.

This issue is most pronounced during periods of above average runoff when the additional flow volume is perceived to be the cause of downstream problems such as flooding of agricultural land, overtopping of road embankments, streambank erosion, and reduced water quality. In the Basin, many downstream residents contend that the upstream drainage of thousands of sloughs resulted in, or at least aggravated, the extreme flooding and related damages that occurred in the spring of 1995.

3.3 Land Cover Changes

Property owners believe that changes in land management practices within upstream portions of the watershed have altered the runoff response of the watershed.

Most of the Basin lies within what is often called the prairie pothole region, a 750,000 km^2 area in the prairie and parkland regions covering portions of southern Manitoba, Saskatchewan, Alberta, and North and South Dakota. European settlement of the Basin began in the 1880s. Prior to this, the land was in its natural state and was inhabited by First Nations people, with a few fur trading posts established after the late 1700s. In the last 100 years this land has undergone tremendous alterations.

Clearing of trees and other vegetative cover, other alterations to land use practices can have a significant effect on the hydrologic response of a watershed. The majority of the land within the Basin is cropland. Generally, as more wetlands are drained and more native parkland is converted to cultivation (with clearing of bush and grasslands) the hydrologic response of the area will likely be altered.

The development of an extensive road infrastructure within the Basin plays an important role for agriculture. This same road network may also have an effect on the hydrology of the Basin. The design and construction of roadways require drainage of the road bed. These road ditches are linked to natural runs and watercourses. Thus, surplus water is removed from the road edges. It is also possible to drain wetlands that are in the close proximity to these ditches.

3.4 Flooding

Flood damage often occurs because of inappropriate development and land use in flood prone areas.

Floods are a natural occurrence. Nature's response to flooding is the evolution of flood plains along streams and the development of shores and beaches around lakes.

Where incompatible developments and land uses occur on these flood prone lands, flood damages can be expected to occur. However, where drainage of wetlands has occurred upstream of the damage site, the tendency of the landowners is to point to the drainage of upstream lands as the cause of the flood event with the resulting flood damage rather than examining the appropriateness of their own use and development.

The hydrology of the prairie region is extremely cyclic. There are extended periods of drought and periods of excess surface water. During low runoff years there is a tendency to 'encroach' onto areas which are periodically subjected to flooding.

3.5 Lake Management

Conflicts have risen between various user and interest groups over the management of lake levels.

During above average runoff conditions reservoirs may have inadequate outlets or downstream channel capacities to permit effective management of water levels. This is further complicated by the loss of upstream wetlands and their associated potential storage capacities resulting in increased runoff volumes being released downstream.

3.5.1 Fishing Lake

The high water levels of 1997 and subsequent years have seriously affected cabins and property developed for recreation located below the natural spill elevation of the lake. Many cabins have

been, or will be destroyed as a result of the high waters. Beaches have been inundated. Septic tanks are under water and their contents have escaped.

Some people perceive that drainage and land use changes in the Fishing Lake watershed have raised the normal water regime of Fishing Lake and thus are partially responsible for high water levels. In times of drought the converse is true, people appreciate more runoff from drainage to enhance water supply to the lake. In the 1960s, a plan was developed which would have diverted water from Milligan Creek, which drains into Little Quill Lake, to Fishing Lake in order to raise lake levels.

In the late-1990s, the problem of high water levels led to the proposal of an outlet control structure and ditching to the Whitesand River with the intention of lowering the spill elevation of Fishing Lake (Sask Water, 1997). This was intended to provide flood protection to property around the lake. Some downstream effects, due to lowering the spill elevation of Fishing Lake and increasing the release of water, were identified. The water quality of Fishing Lake has a high sulphate component and to add this water to the Whitesand River may possibly affect downstream uses. Manitoba also expressed concerns over the water quality and the additional volume of water which would enter Lake of the Prairies.

3.5.2 Good Spirit Lake

The Good Spirit Lake Watershed Association was established in 1986 to sponsor development and operation of flood control works to stabilize lake levels and to ensure adequate outlet conveyance capacity. Prior to the construction of the outlet control structure in 1990, the lake had a history of dramatic water level fluctuations. Periods of high runoff resulted in flood damages around the lake and to downstream agricultural lands. Low runoff has also been a concern for the recreational interests around the lake. There are differences of opinion among lake users on the optimal level of the lake. Another concern stems from the lack of cottage owner representation on the watershed association board.

The Watershed Association conducts a fall and winter drawdown operation at the lake which is intended to create storage for flood protection for properties around the lake and along the outlet channel. Some residents are concerned that lake levels will not recover in the spring and will have an impact on recreational activities at the lake. The risk in lowering the lake over the winter, based on an anticipated spring runoff, is that if little runoff actually occurs, the lake would be at undesirably low levels for the following summer and possibly subsequent years. Conversely, the outlet capacity of the lake is insufficient to remove large volumes quickly. Lake levels would still remain at flood stage for an extended period.

3.5.3 Lake of the Prairies

Lake of the Prairies provides recreation, flood control, and downstream water supply benefits, each with its own lake level requirements. Thus, managing the lake levels for recreation and water supply uses often conflicts with managing the lake for downstream flood control.

Large lake level fluctuations are not compatible with recreational activities such as boating, swimming and in particular cottage development. Fish habitats may also be affected by lake level fluctuation. Reducing lake level fluctuations to meet recreational interests decreases the effectiveness of the original flood attenuation purpose and results in a conflict over use of the reservoir and its associated management guidelines.

Lake of the Prairies is typically operated over the fall and winter such that storage is available for the management of spring runoff. In November, reservoir operations are planned based on fall precipitation and adjustments are made as the winter progresses based on snowfall accumulation. A typical winter will see in the order of 300,000 dam^3 storage made available for flood storage. From the perspective of managing Lake of the Prairies for flood control, the storage available is well matched to the median runoff of 345,000 dam^3. The wetland storage upstream of the lake is an important element in Manitoba's flood management considerations, and loss of a significant portion of that upstream storage could have implications on the management of Lake of the Prairies for flood control. In the event of large spring runoff the reservoir is subject to extensive surcharging.

The operation of Shellmouth Dam has been restricted by land uses below the dam. When the dam was built, it was originally thought the channel capacity downstream of the reservoir was in the order of 100 m^3/s. During the initial years of operation of Shellmouth Dam, the dam was operated for this channel capacity. Local residents below the dam expressed concerns that the operation of the dam resulted in an increased duration of flooding and inhibited drainage of cultivated areas. The most flood prone area is immediately below the dam for a distance of about 16 km. In this reach approximately 1,800 ha of land were flooded in 1995.

Before construction of the dam, flooding of this land, previously used for hay production, was not critical in that most of the flooding occurred over frozen ground and did not impact farm operations. The operating rules were modified over time to consider a reduced channel capacity and changed land use. Experience indicates flows up to 51.0 m^3/s can be handled by the river and dyking system along the river immediately below the dam without flooding low-lying oxbows now used for crop production and maintaining the water table low enough to allow cropping throughout the valley floodplain. At present an attempt is made to maintain the outflows from the reservoir to no greater than 45.3 m^3/s to permit adequate land drainage. Nevertheless, complaints from landowners in the valley downstream of Shellmouth Dam continue.

4 Drainage History

4.1 Introduction

As land in the Basin was being settled, 'breaking of prairie' and some bush clearing occurred as the region was converted to agricultural cropland. The best agricultural lands were likely selected first. Limited equipment was available and earth moving equipment was as yet, undeveloped. Thus, there was probably very little wetland drainage in the early years.

From the beginning of settlement, it was evident that the growing season in this area was relatively short for grain production. As more people settled the area, the demand for land increased. It was felt that drainage works could make more land productive. Organized drainage efforts were seen as part of the solution. The grouping together of people's efforts and finances began various forms of district drains in these early years of settlement. The North West Territorial Drainage Ordinance was the initiation of the earliest organized drainage works. Since then organized drainage projects have been carried out by provincial and federal agencies, municipal governments, and groups of landowners organized under various provincial legislation. The concept of 'organized drainage', within the Basin, applies more to Saskatchewan than to Manitoba.

By the end of the Second World War, mechanization of farm equipment was accelerating. Earth moving equipment was also rapidly evolving. Equipment was becoming both more affordable and available. Widespread drainage has occurred over the last 50 years. Organized drains provided a common outlet for landowner drainage. There was also an added motivation for landowners to fully utilize these drains, since their lands were being assessed a levy to develop district drains. Also, some government agricultural programs were based on cultivated acres, which resulted in marginal lands being converted to cultivation.

The prairies are a land of weather extremes. There are cycles of drought as seen during the 1930s, 1960s and most recently during the 1980s and early 1990s. Conversely, there are periods of flooding or wet cycles. This occurred in the mid 1950s, mid 1970s and mid 1990s for example. During dry cycles, it is common for flood prone land and semi-permanent wetlands to be converted to crop lands. When so called 'average' conditions return, or a wet cycle begins, these areas are no longer productive. This often initiates drainage activity.

Drainage within the Basin is wide scale. Private drainage works, which are mostly unauthorized ad-hoc drainage on private lands, far exceed the magnitude of drainage by organized works. Legislation and enforcement have been largely ineffective in preventing or controlling drainage of wetlands on private lands.

4.2 Saskatchewan

Settlers in the prairies frequently discovered that agricultural development required drainage of seasonal water and wetlands. It was initially unclear how the law regulated drainage. It was at least the perception in Canada that Common Law hindered drainage schemes, which involved the deposit of excess water into a watercourse or on to a neighbour's property. It was reasonably clear that landowners had the right to drain land to get rid of casual surface water as long as it did not impact flow in a regular or definite water course, but could not easily undertake more ambitious drainage schemes. Although a landowner could not own flowing water he/she could have certain rights of access and use, known as a "riparian right" if land bordered upon the flowing water. The ordinary law of Riparian Rights prevented a landowner from draining lands into a watercourse if the drainage resulted in an appreciable change in the quality or the quantity of water in the watercourse and a landowner could not divert water onto a neighbouring land. Common Law, consisting of rules, principles, customs, and precedent were developed in England and was used as a basis for the development of decisions. It is generally known as unwritten law. Common Law doctrine meant that flowing water was a common resource and could not be the subject of property.

Common Law and Riparian Right may have worked well in England and eastern Canada; it did not work well in the prairies. Common Law can be changed or replaced by statute. Prior to Saskatchewan becoming a province in 1905, the territory was sparsely populated. Early federal legislators capitalized on that with the introduction of the *Northwest Irrigation Act* of 1894. In essence, the federal government seized ownership of a resource, which up until that time was considered to be incapable of ownership by anyone, including the crown.

- **The *Northwest Irrigation Act*** of 1894, by the Government of Canada, provided a presumption that grants of crown land did not vest in the grantee any property or interest in the bed or shore of a water body, river, or stream. The Prairie provinces entrenched this principle in early water legislation and in *The Provincial Lands Act*. Saskatchewan's position is still based on water and lands legislation. Only those people who own land under title derived from a crown grant prior to 1894 have claim to beds and shores of a water body. Consequently most individuals do not own the beds or shores of remaining water bodies within or adjacent to their land, even though this is not evident on the land title. In Saskatchewan, it can be argued that the Crown owns the bed of virtually every current or former water body, although in practice this has not been pursued.

  The *Northwest Irrigation Act*, designed to encourage irrigation, introduced a licencing scheme that in theory regulated virtually all significant drainage projects. All persons were forbidden to divert or use any water from any water course/body except under authority of the Act. Therefore anyone contemplating significant drainage required a statutory licence. In 1919, amendments to establish special procedures for approval of drainage projects without the necessity of issuing a formal water licence were passed by the Federal Government.

- ***The Drainage Act*** of 1909, by the Government of Saskatchewan, proclaimed the creation of drainage districts was possible upon the presentation of a petition to the Lieutenant Governor In Council by the owners of 2/3 of the area of affected landowners. The Minister of Public works retained the power to establish the assessment for the benefitted lands. Drainage works were constructed as local improvements under government supervision and were maintained by local municipalities. The major function of the Drainage District was to initiate the project and issue debentures. Twenty-six projects were constructed in the province between 1912 and 1930. *The Drainage Act* created an incentive to large scale drainage by removing a major obstacle to communal action.

  The Drainage Act was repealed with the coming into force of *The Drainage Control Act* on January 1, 1981. However, the provisions for operation and maintenance were retained. Over time the function of Drainage Districts legislation was assumed by *The Conservation and Development Act* (1949) which allows the creation of Conservation and Development areas either upon petition or at the Minister's discretion for purposes that include drainage.

- ***The Private Ditches Act*** of 1909 was designed to permit drainage of private land distant from any watercourse. A landowner who wished to construct drains was required to get agreement from all those whose lands would be affected. A project could not cross a municipal road or pass through or into more than 10 quarters of land. The landowners were to apportion the work and materials for the ditch among themselves. A successful agreement was filed with the RM and forwarded to the Minister responsible. If negotiations were unsuccessful, the proponent could ask the RM to appoint an engineer to assess project feasibility. The engineer could arrange for the work and have the cost charged back to the land of an uncooperative landowner through municipal taxes. Sixteen projects were undertaken in the province between 1916 and1930. *The Private Ditches Act* was repealed with the proclamation of *The Drainage Control Act* on January 1, 1981.

- Prior to 1930, the federal government retained ownership and control of all public lands, natural resources, and water that had not yet been granted. The province though held some control over the drainage of land. This divided jurisdiction caused problems with reclamation of wetlands/swamp lands that inhibited settlement of districts containing large areas of those lands. Problems were resolved by negotiations with the Government of Canada resulting in an agreement which was confirmed by the enactment of ***The Reclamation Act (1919)***. This Act vested control of drainage in the level of government that held the dominant interest in a particular project. In a provincial drainage district the province could acquire vacant crown land and after project completion sell the lands to recoup costs. If the Federal government wished to drain Federal land, provincial drainage district legislation applied and treated the Federal Government as an ordinary landowner provided they agreed to sell once a drainage project was complete. The clear purpose of reclamation legislation was to increase the agricultural land base. Reclamation legislation was later repealed when water resource management was transferred to the province in

1930 and thereafter drainage of agricultural lands became an entirely provincial responsibility.

- In 1930-31, the provisions of the *Northwest Irrigation Act* and subsequent amendments were transferred from the federal government virtually intact into the water resources law of the Prairie provinces. The first regulatory water resource statute was ***The Water Rights Act*** of 1931.

- Amendment of ***The Water Rights Act*** in 1935 prevented anyone from diverting or impounding "any surface water not flowing in a natural channel or contained in a natural bed", or from constructing works for those purposes without a licence. The Minister was empowered to remove any unlicensed obstruction to water flow, and Saskatchewan's legislation reversed the Common Law position by allowing any person who was harmed by unauthorized drainage or impoundment to sue for any resulting loss. The combination of the original *Water Rights Act* and the 1935 amendments allowed the regulation of all drainage projects, although in practice licences were not obtained for the vast majority of drainage works. *The Water Rights Act* was put in place as a vehicle for permitting the licensed use of water in an orderly fashion, but contrary to what most people believed, it was not intended to deal with drainage and flooding. Therefore, there was continued absence of a statute or "law" regulating private drainage. The only recourse by any one impacted and damaged by unauthorized drainage was negotiation and altercation with the offending party, or civil action in the courts. The courts then had to continue to rely on application, interpretation, and precedence of interpretation of the principles of Common Law.

- The effects of the extent of drainage that occurred in subsequent years without authorizations brought significant pressure to bear on the government and in the late 1970s a public advisory committee was struck. In 1979, a temporary moratorium was applied to organized drainage projects seeking provincial funding under the Water Control Assistance Program as provincial approvals were not required at that time for drainage works.

- After an extensive public consultation program, recommendations of the committee ultimately led to enactment of ***The Drainage Control Act*** in 1980 which supplemented the wide powers of *The Water Rights Act* by prohibiting the construction or operation of any drainage works without a permit. This statute then and thereafter replaced the principles and application of Common Law governing private drainage. The Act also established the principle that a person who constructed or operated unauthorized works was liable for any resulting damage, injury, or loss suffered by others. It provided a mechanism to resolve drainage and flooding problems through a complaint procedure, instead of through the courts. It also provided a mechanism to appeal any decision, order, or action under the Act.

- In addition to the new legislation, the Province developed interim guidelines (1983) for drainage in the Basin above Kamsack. These guidelines removed the moratorium and set conditions by which projects could be developed.

- ***The Water Corporation Act*** of 1984 was an amalgamation of the essential provisions of *The Drainage Control Act* with the framework of *The Water Rights Act*. With the passage of *The Water Corporation Act*, *The Drainage Control Act* was repealed. The Water Corporation was now charged with authorizing diversion and use of water and with issuing drainage approvals. The regulations and provisions of *The Drainage Control Act* dealing with drainage complaints were transferred to and became the responsibility of Sask Water. The Act then became a complete code of conduct governing drainage in the Province. Despite the ample regulatory provisions found in this legislation, problems with unapproved private drainage persist to present day.

4.3 Manitoba

One hundred years ago, about one million hectares of what is now considered to be prime agricultural land in Manitoba was too wet to support settlement and sustain production of annual crops. This is very significant in that there are only about 5.5 million hectares of improved cropland in the Province today. The purpose of agricultural land drainage in Manitoba is to remove, during the growing season, water that is in excess of the needs of crops and which, if not removed within a certain time period, could either destroy crops or substantially reduce yields.

Early settlement in Manitoba was generally located along the river channels and in well drained areas in the Red River Valley. The land immediately adjacent to the rivers often had good natural surface drainage because the land had been built up by sediment deposition during periodic floods. As suitable well drained lands came to be in short supply attention inevitably turned to the poorly drained lands such as the Boyne Marsh, the St. Andrew Bog and the Elm Creek Bog in the Red River Valley. Drains were constructed to the rivers or their tributaries. As drainage and agriculture extended further west, something had to be done about the runoff from the Escarpment. The solution was floodways to capture these flows and confine them until they reached the Red River or a tributary. These were at first simple double dykes that were raised in long parallel lines, usually along road allowances, with the water flowing above ground level in between. The floodways allowed local drainage systems to be constructed to handle local rainfall without having to also carry escarpment runoff.

Early land drainage development focused in the Red River Valley. This was deliberate in that it is there that the largest requirement existed. Manitoba's early drainage legislation developed out of the need to improve the clay soils in the Red River Valley. The development in the Red River Valley influenced attention to drainage development in other places.

The western pothole region of Manitoba in which the Basin is located is characterized by generally good farmland pock marked by random scattering of pothole depressions. These generally retain water and lack natural waterways readily available to serve as outlets for

drainage. This topography also is attributed to glacial influence as the glaciers receded and melted in this region. There has been, and continues to be, a lack of any provincially driven organized drainage activity. However, there are many unorganized drainage activities taking place on individual land holdings. This activity has increased in more recent years with the advent of larger field equipment, and availability of equipment capable of carrying out drainage. Sometimes ad hoc municipal drainage works support this activity where these can be located on road allowances.

- ***The Water Rights Act*** of 1930 is the major water resource regulatory instrument requiring that all diversions of water must have a license. The Act was rewritten in 1987 and was amended in 2000. The Act reflects the responsibility of the province, as owner of the resource, for ensuring that water management activities take into consideration the impacts of these actions on people, the water resource, other resources, property and infrastructure. The Act states no person shall use or divert water or construct water control works unless they hold a valid and subsisting license to do so. All property in and all rights to the use or diversion of all surface and groundwater are vested in the Crown in the right of Manitoba. The use, diversion and the construction of water control works require a water rights license. Water control works includes the drainage of agricultural land and flood control works.

- Under ***The Municipal Act*** municipalities can pass bylaws requiring that drainage works are licensed or permitted by the municipality. Under the Act, municipalities are responsible for all municipal drains, which the municipality has constructed or maintained and have authority over all drainage in their municipality with the exception of provincial waterways.

- ***The Watershed Conservation Districts Act*** was enacted in 1959. Conservation districts permit a number of municipalities to co-ordinate their efforts with respect to all aspects of water management, including drainage. It was amended in 1976. Under this legislation, municipalities could organize and petition the government to establish a conservation district made up of a number of municipalities, or portions of them, as a framework to carry out programs for "...the conservation, control, and prudent use of resources..." One of the resources was water. In terms of drainage, a district would assume ownership and control of all waterways within the district boundary (certain more recent districts were formed without responsibility for drainage). To date the districts have chosen to have no regulatory authority over landowners. They have exercised their influence by persuasion or with incentive grants. Generally they have tried to set up good models and create good ethics with respect to drainage in relation to land use. However, this may be changing as one district has opted to take on a greater regulatory responsibility by dealing with drainage complaints and only referring them to the province for enforcement if they cannot be resolved. Provincial policy is to pursue the formation of additional districts.

- Changes to the farm economy requiring cropping changes to more specialized higher valued crops, the return to a wetter cycle in the 1990s, the increased size of farms and machinery, the narrower profit margins, and the availability of earth moving equipment

resulted in producers carrying out on-farm drainage activity as they had never done before. The outcome of this combination of events was that landowner/landowner conflicts, municipal/landowner conflicts and municipal/municipal conflicts were increasing. The Province was blamed for not settling these disputes by simply enforcing *The Water Rights Act*. The lack of knowledge and presence of drainage expertise resulted in some works being constructed that were damaging to the environment, other producers, or to public infrastructure. This tended to confirm to many that drainage was the problem and that something had to be done to stop it.

- The Land Drainage Review was initiated in fall of 1996. The review was to address concerns of government and other stakeholders about difficulties, which had emerged with the program over the past years. The following is an outcome of this review.

The province responded by:

- Enforcing *The Water Rights Act*, which requires licenses for all drains (coordinate/enforcement with municipalities, conservation districts and resource agencies).

- Regionalizing drainage and putting in place regional water managers with supporting staff to work with municipalities to enforce *The Water Rights Act* and to work with local governments in achieving a coordinated approach.

- Encouraging the formation of Conservation Districts. The number of districts has practically doubled in the last few years and currently districts represent half of agricultural Manitoba.

- Where Conservation Districts do not exist, encouraging the formation of water management associations. The Red River sub-basin in Manitoba is entirely represented by associations, all at very preliminary stages in their evolution.

The municipal response has been to:

- Start working with neighboring municipalities and the Province on a watershed basis to start to address the systems approach to drainage and to work together with the Province on enforcement;
- Increasing compliance with *The Water Rights Act*, and encouraging landowners to do the same; and,
- Begin to discuss the formation of a Conservation District.

4.4 Interprovincial

Interprovincial drainage concerns have been a long-standing contentious issue between Manitoba and Saskatchewan, especially in the Russell/Langenburg area over the past 20 years. On several occasions this interprovincial drainage issue has been referred to the Prairie Provinces Water

Board (PPWB), which has a mandate to address interprovincial water management issues. However, no acceptable resolution has yet been reached through that forum.

The PPWB was formed in 1948. The Prairie provinces of Alberta, Saskatchewan and Manitoba and the Federal government established this board to recommend the best use of interprovincial waters and to recommend water allocations between provinces. In 1969, the members signed the 'Master Agreement on Apportionment' which contains a formula based on the principle of equal sharing of available water on the prairies. Alberta and Saskatchewan may each take up to one half of the natural flow of water originating within its boundaries and one half of the flow entering the province. The remainder is left to flow to the downstream jurisdiction. The PPWB has one representative each from Alberta, Saskatchewan, and Manitoba, and two members from the Federal Government.

The following is a summary of discussions and decisions of meetings of the PPWB on the issue of interprovincial drainage.

- In 1979, the Board agreed to conduct the Assiniboine River Natural Flow Study (PFRA, 1980). There were concerns raised as to whether drainage and road construction affected the hydrograph. A literature search was to be conducted on the effects of drainage on prairie hydrographs. Later that year, it was recognized that limited knowledge existed for prairie hydrology and there were no adequate technical means of determining the effects of drainage. The Committee on Hydrology (COH), a technical committee of the PPWB, was asked to develop an applied research program that might determine the effects of artificial drainage on downstream flows of prairie streams. It was at this time that a temporary moratorium was applied to organized drainage projects in the Saskatchewan portion of the Basin.

- In 1980, the Board agreed to accept a reference prepared by Manitoba and Saskatchewan on interprovincial drainage in the rural municipalities of Churchbridge and Langenburg in Saskatchewan and Shellmouth and Russell in Manitoba. It was agreed to prepare a detailed report and recommendations on the drainage issue via the Saskatchewan-Manitoba Interprovincial Task Force on Drainage.

- In 1981, the COH agreed to develop procedures to monitor drainage projects in interprovincial drainage basins.

- In 1983, the Board adopted the COH report "A Recommended Procedure to Deal with the Impact of Artificial Drainage on Downstream Flows". The method in this report has since been used by water resource agencies to assess the impacts of drainage on stream flow, and remains the standard of practice to this day.

- In 1987, the Board accepted the report " Interprovincial Drainage Affecting the Rural Municipalities of Churchbridge and Langenburg in Saskatchewan and Shellmouth and Russell in Manitoba" by the Interprovincial Task Force on Drainage. During discussions,

members noted that the resolution of specific problems would come through bilateral discussions.

- In 1993 the Langenburg East Flood Control Project was proposed. Public concerns were expressed. The Board determined that bilateral discussions between the two provinces concerning this project were necessary. The COH concluded that the project had no impact relating to apportionment.

- In 1995, Sask Water provided an Environmental Impact Assessment report on the proposed Langenburg East project to the Board.

4.5 Current Inventory

4.5.1 Saskatchewan

In Saskatchewan two options are availabe for a group of landowners to develop organized drainage projects. These are formation of a Conservation and Development Area Authority (C&D) or a Watershed Association (WSA).

A Conservation and Development Area Authority is established by a 'petition' process whereby a minimum of 66 2/3 percent of the registered landowners within the watershed boundaries support the formation. Once the establishment occurs, all lands within the administrative boundary are enrolled in the C&D. The Authority and Sask Water share the costs for programs of the C&D. The Authority raises funds for administration costs, construction or program costs and maintenance costs through an assessment via the RM tax system. The 'works' or 'projects' which a C&D can participate in are extremely diverse and far reaching, essentially anything that is necessary to save, conserve, or develop any land or water resources within the watershed. However, historically the C&Ds have focused on drainage works. Sask Water will provide technical and financial assistance to the Authorities. The following table summarizes the C&D boards currently active within the Basin.

Table 4.1 - Active Saskatchewan C&D Authorities in the UARB

Name	Rural Municipality	Length of Major Ditches (km)	Assessment Area (ha)
Buchanan C&D #51	274, 303, 304	97	29,192
Good Lake C&D #94	274, 304	90	4,481
Burgis C&D #134	274	71	2,626
Hohenlohe C&D #149	181	14	839
Langenburg East #171	211	0*	3,623
Marchwell South #172	181, 152	2.4	5,704
Total Assessed Area			**46,465**

* Some ditch has recently been constructed within this C&D, however the construction has not received Sask Water approval.

The total assessed area of the C&Ds represents about 6.6 percent of the Basin within Saskatchewan.

The other option is to form a Watershed Association. The prime difference between a WSA and a C&D is that the membership of a WSA is composed of agencies, whereas a C&D is composed of individual landowners. The agency can be the council of a city, town, village, rural municipality, or the governing body of a corporation or other duly constituted organization. The forming agencies apply to establish a Watershed Association rather than being established by a petition process of the local ratepayers. The mandate is somewhat similar to the C&D but the scope of a Watershed Association is broader. Often the focus of a WSA is beyond drainage and flood control and usually extends beyond agricultural benefits as well. Sask Water will provide technical and financial assistance to the local Watershed Associations. The following is a summary of the Watershed Associations located within the Basin.

Yorkton Creek - Watershed Association Board No. 4

Member Agencies
- City of Yorkton
- City of Melville
- RM of Wallace #243
- RM of Orkney #244
- RM of Cana #214
- RM of Saltcoats #213
- Village of Willowbrook
- Crescent Lake Grazing Coop
- York Lake Regional Park

Good Spirit Lake - Watershed Association Board No. 6

Members Agencies
- RM of Buchanan #304
- RM of Invermay #305
- RM of Good Lake #274
- RM of Insinger #275
- Good Lake C&D #94
- Buchanan C&D #51

Fishing Lake - Watershed Association Board No 7

Members Agencies
- RM of Sasman #336
- RM of Foam Lake #276
- Resort Village of Chorney Beach

Smith Creek Regional - Watershed Association Board No 8

Member Agencies
- RM of Churchbridge #211
- RM of Langenburg #181
- RM of Spy Hill #152
- Hohenlohe C&D #149
- Langenburg East C&D #171
- Town of Langenburg

Individual landowners can also construct drainage works on private lands. If the water of the drained area leaves the parcel of land then the landowner is required by *The Water Corporation Act* to obtain an approval from Sask Water to construct and or/operate private drainage works. For the most part this legislation has been ignored by the landowners. Discussions with the Sask Water staff at the Yorkton Regional office concluded that unauthorized drainage work far exceeds licensed works. The staff felt that more than 95 percent of all drainage activities being conducted were unauthorized. There have been 90 private drainage projects approved to operate with a further 45 projects approved in the Basin in Saskatchewan.

4.5.2 Manitoba

In 1976, *The Watershed Conservation Districts Act* of 1959 was amended. This Act was based on watersheds and focussed not only on water, but also of equal importance, it encompassed soil, wildlife, forestry and fisheries. The Conservation District (CD) was to provide planning for both the short and long-terms.

In general, a CD is primarily locally driven, with very little involvement from the provincial government. It is an organization of people co-operating to manage the natural resources of their area. Boundaries are based on watersheds and/or RM borders. Originally the plan was to utilize only watershed drainage boundaries. CDs are now using RM borders as the main external perimeter with the internal boundaries based on watersheds. The CD Board hires a local manager. The Conservation Districts receive 75 percent of their funds as a direct grant from the provincial government. The other 25 percent is raised via a local tax levy. The CD can also receive grants from other agencies, governments and local participating landowners (all of which would be additional to their budget).

Although the Province of Manitoba has a long history of organized drainage, only a small portion of the Basin, which is within the RM of Ellice, falls within a Conservation District (Upper Assiniboine River Conservation District). However, farmers in this area of Manitoba are similar to their neighbours across the provincial border to the west in that extensive private drainage of wetlands, where physically feasible and viable, has occurred over time.

4.6 Summary

This chapter has considered the background against which landowners have made and currently make decisions regarding land clearing, cropping practices, and wetland drainage. In summary:

- Saskatchewan has water rights legislation which ensures that water cannot be drained without statutory approval.

- There has been and continues to be a prevailing public attitude that wetlands amount to nuisances.

- Proponents of drainage projects in Saskatchewan have come to expect that they will be able to construct their projects with minimal government interference, whether they seek approval or not. This expectation reflects strongly held views about the right of property owners to manage their lands as they see fit.

- Over the years, the vast majority of drainage projects in the Basin have proceeded without authorization.

- In the Manitoba portion of the Basin, *The Water Rights Act* is the major regulatory water resource legislation applying to the regulation of agricultural land drainage. *The Conservation District Act* could be used if desired for regulation. Municipalities can pass bylaws under *The Municipal Act* requiring that drainage works are licensed or permitted by the municipality.

- Producers feel compelled by climatic conditions in the Basin and the economics of current agricultural production to maximize cultivated area and crop options. Recommendations to address drainage and changes to the Basin landscape cover should acknowledge these forces.

- Limited resources available to provincial regulators have prevented effective enforcement of existing legislation in Saskatchewan. It appears that either new legislation and/or adequate resources are needed to establish an effective regulatory environment for drainage.

- Each province has established local authorities with some degree of power over drainage development and with cost-sharing formulae between the province and the local authority. However, organized works likely represent only a small proportion of drainage activity in the Basin.

- Drainage in watersheds which cross the provincial boundary has been investigated by the PPWB and reports have been written containing alternatives for regulating such drainage. However, this issue remains unresolved.

5 Land Cover

5.1 Introduction

When the first European fur traders began exploring the area in the mid-eighteenth century they encountered extensive grasslands with a scattering of wetlands and aspen bluffs. The Touchwood Hills in the western portion of the Basin were well vegetated by large tracts of aspen. The Boreal area in the north had mixed-wood forests of spruce, aspen and birch. Settlement of the area and the subsequent conversion of grasslands to cultivation began around 1880 and accelerated through the early twentieth century. Historical accounts speak of very few trees in the Basin at the time of settlement. The aspen bluffs presently located throughout areas of intense agriculture are said to be the result of the absence of earlier, wide-scale prairie fires.

The Basin underwent extensive land use changes as a result of settlement for agriculture. This conversion was in part the result of deliberate immigration and settlement policies, wetland drainage policies (as discussed in Chapter 4), and agricultural programs and policies.

When the prairies were originally settled in the late 1800s and early 1900s, the purpose was for agricultural development. Under the *Homesteads Act*, an individual could gain ownership of a quarter section of land by living on that quarter and by breaking it for crop production. Even the original surveying of the prairies, where the landscape was divided into a huge grid system of quarter sections, influenced land use. Roads were built on this grid system, often regardless of whether the road passed through a wetland, tree bluff, or hilly terrain.

After the original settlement of the prairies, governments continued to encourage cultivation through farm programs. The intent of most agricultural programs was to bolster farm income. These programs provided financial support to producers for growing grains, oilseeds and more recently, specialty crops. By supporting these crop sectors, assistance programs favoured cultivation over other land uses. For example, in 1986 the federal government introduced the Canadian Special Grains Program, a one time, one billion-dollar payment to Canadian producers to compensate them for low grain and oilseed prices. Only farmers growing grains and oilseeds received aid. Another example, the Gross Revenue Insurance Program (GRIP), was in effect from 1991-1994. GRIP provided financial support for the grains, oilseeds, and special crops sectors. By assisting these sectors, GRIP continued to encourage cultivation over other agricultural land uses such as hay and pasture.

There were other government subsidies and institutional policies, in conjunction with farm income support programs, that influenced land use. The Canadian Wheat Board's (CWB) acreage-based, quota allocation was established to give every farmer, fair access to market their grain. By using cultivated acres to calculate a farmer's allocation or quota, producers could increase their allocation by bringing more acres under cultivation. The incentive of increased allocations may have encouraged producers to drain wetlands, break native grasslands, and clear trees. In the 1994/95 crop year, the CWB changed from a quota allocation, based on cultivated

acres, to a direct contract system. The contracting system does not create the motivation to convert additional acres to cultivation.

The *Western Grain Transportation Act* (WGTA) lowered the farmers' cost of transporting grains and oilseeds to an export location, making grain and oilseed production more profitable. With relatively higher profits from growing grains and oilseeds compared to other land uses, producers had incentive to increase their acreage seeded to grains and oilseeds by breaking land considered marginal for crop production. The WGTA was repealed in 1995.

In recent years, governments have moved to a 'whole farm' approach for income support programs. For example, since 1994, the Net Income Stabilization Account (NISA) program includes all farm commodities except those under supply management. The Agricultural Income Disaster Assistance (AIDA) program is in place to stabilize income from all farm sources. These more recent programs have little effect on land use decisions made by the agricultural sector.

The net effect of this conversion of native prairie landscapes to agricultural production is that nearly three-quarters of the Basin area is now used for agriculture. The next three sections examine the current, and where possible historic, land cover data for agriculture, treed, and wetland areas respectively. The final section in this chapter examines the mathematical relationship between wetland area and wetland storage volume.

5.2 Agricultural Land Cover

Statistics Canada has conducted a national census every five years. In addition to recording population and distribution by rural municipality (RM), land use categories were also reported. Table 5.1 was prepared from census data on RMs located in the Basin. Table 5.1 shows that the average farm size in the Basin has doubled (110 percent) since 1956. There has been a corresponding decrease in the number of farms. Over the same period, the rural population has fallen from 57,600 to 23,200 representing a 60 percent decrease since 1956.

Figures 5.1 and 5.2 represent the distribution of land use on an 'average' quarter section of land in 1956 and 1996. Comparison of these two figures shows a nearly 50 percent reduction in 'unimproved' area. This represents lands which are not broken, cleared or drained, basically natural parklands. There has been an accompanying increase in improved lands, that is, annual seeded crop of 67 percent from 1956 to 1996.

Table 5.1 - Comparison of the Average Farm for 1956 and 1996

Land Use	1956	1996
Average Farm Size	163.5 ha	345.6 ha
Annual Seeded Crop	52.5 ha	186.4 ha
Summer Fallow	30.8 ha	35.8 ha
Tame Hay	2.8 ha	22.3 ha
Seeded Pasture	3.0 ha	19.8 ha
Total Improved	91.6 ha	264.3 ha
Total Unimproved	71.9 ha	81.2 ha
Total Number Of Farms	13,873	6,578
Approximate Rural Population	57,600	23,200
Approximate Urban Population **	33,300	43,000

** includes Cities, Towns & Hamlets

Figure 5.1
Agricultural Statistics for 1956

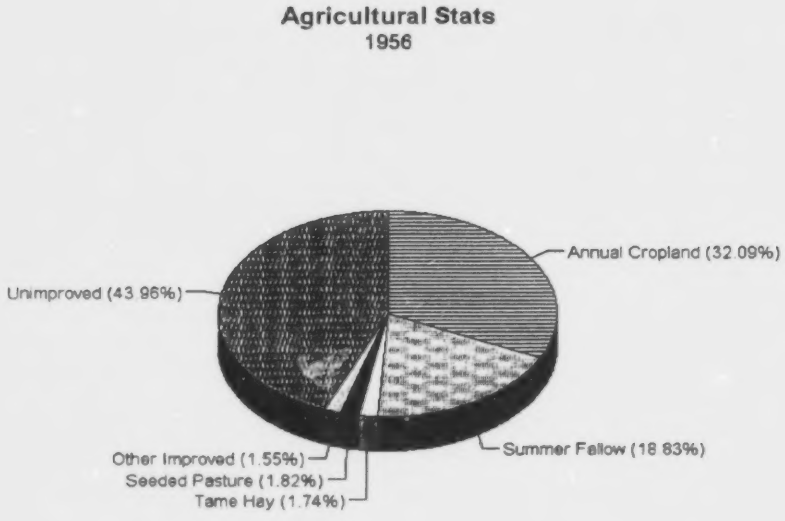
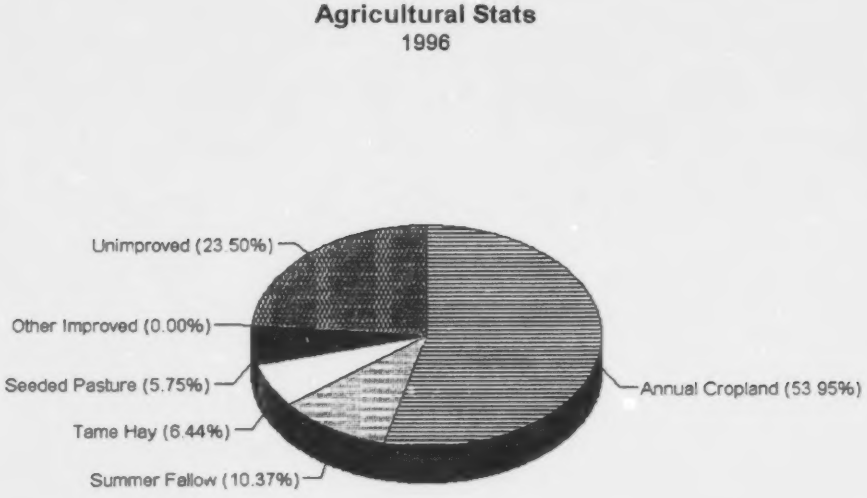


Figure 5.2
Agricultural Statistics for 1996



5.3 Woodlands

Maps of the Basin area by the National Topographic Survey (NTS) exist for two different time periods. The primary features of interest on these maps are wooded area, and water. Man-made features such as roads, buildings, towns, pipelines, etc., are also shown but occupy very little of the total Basin area.

Delineation of wooded areas in the Edition 1 NTS maps (circa 1960) was based on the following criteria: 'areas with perennial vegetation that is at least six feet in height'. The Edition 2 (circa 1990) guidelines for wooded areas are essentially unchanged. Therefore, assuming the criteria were applied consistently in both NTS map editions, the maps should provide a reasonable, albeit coarse, estimate of woodland loss between the two time periods.

The NTS map editions do not represent a single "snap-shot" in time. Depending on the availability of photography, a single NTS map sheet may be compiled from photos spanning a number of years. Furthermore, adjacent sheets may have similar publication dates but may have been compiled from different years of photography. For the Basin, Edition 1 NTS map sheets were constructed from photography acquired during the 1950s (1949 through 1960), with Edition 2 being compiled from 1980s (1979 through 1990) photography. For the purpose of this analysis, it was assumed that Edition 1 and Edition 2 represented the 1950s and 1980s conditions respectively. Changes detected by this analysis were conservatively considered to have occurred within the 20 year interval (1960 to 1979) between editions, although any such change could have occurred at any point along the 41 year record of photography (1949-1990).

Historical (1956-1996) trends in the agricultural census clearly illustrate the tendency toward larger average farm sizes and the overall increase of improved agricultural land in the Basin (see Table 5.1). This extension and intensification of agricultural activity has had significant impacts on the abundance and distribution of woodland features in the Basin.

The analysis in this section was the six watersheds used to structure the Local Watershed Committees (see Figure 5.3). Table 5.2 presents the woodland area and number of woodlands by watershed and for the entire Basin for the two time periods. Table 5.3 assesses the loss of woodland area and numbers for each watershed and for the Basin.

Table 5.2 - Woodland Trends - Historical Comparison

Watershed	Watershed Area (ha)	Woodland 1950s			Woodland 1980s		
		Number	Area (ha)	Percentage	Number	Area (ha)	Percentage
UPPER ASSINIBOINE	328,700	3,080	129,900	39.5	2,250	91,100	27.7
UPPER WHITESAND	428,300	6,100	111,300	26.0	4,340	58,900	13.8
LOWER WHITESAND	306,100	5,350	43,700	14.3	2,920	26,300	8.6
LAKE OF THE PRAIRIES	490,200	5,440	200,500	40.9	2,320	191,400	39.0
YORKTON CREEK	232,400	6,370	24,100	10.4	2,970	14,300	6.2
LOWER ASSINIBOINE	328,500	6,750	53,800	16.4	3,980	38,900	11.8
Basin Total	2,114,200	33,090	563,300	26.6	18,780	420,900	20.0

Table 5.3 - Woodland Trends - Woodland Loss

Watershed	Woodland Loss Number	Woodland Loss Area (ha)	Percent Loss (Number)	Percent Loss (Area)
UPPER ASSINIBOINE	830	38,800	26.9	29.0
UPPER WHITESAND	1,760	52,400	28.9	47.1
LOWER WHITESAND	2,430	17,400	45.4	39.8
LAKE OF THE PRAIRIES	3,120	9,100	57.4	4.5
YORKTON CREEK	3,400	9,800	53.4	40.7
LOWER ASSINIBOINE	2,770	14,900	41.0	27.7
Basin Total	**14,310**	**142,400**	**43.2**	**25.3**

Figure 5.3
Local Watersheds

Canada

PFRA ARAP

Based on a comparison of woodlands from the two editions of the NTS maps shown in Tables 5.2 and 5.3, all areas of the Basin have experienced a significant reduction of total area and number of woodlands. Over the entire Basin, 142,400 ha of woodland area and 14,310 individual woodland features have disappeared from the NTS map record. This represents a 25 percent reduction of woodland area, and the elimination of 43 percent of contiguous woodland features originally delineated by the Edition 1 NTS maps. Table 5.3 illustrates a significant reduction of woodland number and size in every watershed, with the most dramatic areal loss occurring in the Upper Assiniboine and Upper Whitesand watersheds. In these two watersheds, combined woodland loss totals approximately 91,200 ha representing 64 percent of total woodland loss for the entire Basin. It is interesting to note that all watersheds, with the exception of Lake of the Prairies, experienced percent loss of area greater than the Basin average. This is because the Lake of the Prairies watershed has such a large woodland area in comparison with the other watersheds and relatively little lost in area between the two time periods (see Table 5.2).

The percent reduction of woodland number is most significant in the Lake of the Prairies, Yorkton Creek and the Lower Whitesand watersheds. All of these watersheds experienced proportional feature loss much greater than the Basin average. Combined feature loss in these watersheds accounts for 62 percent of woodlands removed from the entire Basin. However, as shown in Table 5.3, Lake of the Prairies reveals an interesting trend, where a dramatic decrease of woodland number results in a relatively small reduction of woodland area. This trend observed in the Lake of the Prairies is anomalous to the other five watersheds and the average condition observed for the entire Basin.

The areal loss of woodlands and reduction of woodland numbers has created some interesting trends in density (number of woodland areas per square km) and average size as shown in Table 5.4. Across the entire Basin, changes to the landscape have increased the average size of woodlands while decreasing the density. This trend is evident in the Basin average and in all but two watersheds. Both the Upper Assiniboine and Upper Whitesand watersheds experienced a slight decrease of average woodland size while still maintaining the general trend of decreasing density. Lake of the Prairies has experienced the most dramatic change to average size and density. Removal of small, isolated woodlands in this watershed has increased average woodland size by 125 percent and has reduced woodland density by 58 percent.

A number of similarities between watersheds become evident upon review of the data trends. Both the Upper Assiniboine and Upper Whitesand watersheds had a high percentage of bush cover in the 1950s relative to the Basin average, accompanied with relatively low woodland numbers. Thus, the average woodland in these watersheds was much larger than the Basin mean, translating into a relatively low woodland density when compared to the rest of the Basin. Furthermore, the percentage loss of woodland area is much higher than the Basin average while the percent loss of woodland features is significantly lower than the Basin average. Taking these trends into account, it is clear that historically (NTS Edition 1 map) these watersheds were dominated by few, large, contiguous areas of woodland that have been significantly impacted over the period in question. Furthermore, encroachment on these woodland areas has reduced these large contiguous areas to a series of smaller, more isolated, remnant cores.

Table 5.4 - Woodland Trends - Pattern

Watershed	Mean Woodland (ha) 1950s	Mean Woodland (ha) 1990s	Woodland Density 1950s *	Woodland Density 1980s *
UPPER ASSINIBOINE	42.1	40.5	0.94	0.68
UPPER WHITESAND	18.3	13.6	1.42	1.01
LOWER WHITESAND	8.2	9.0	1.75	0.95
LAKE OF THE PRAIRIES	36.9	82.4	1.11	0.47
YORKTON CREEK	3.8	4.8	2.74	1.28
LOWER ASSINIBOINE	8.0	9.8	2.05	1.21
Basin Total	**17.0**	**22.4**	**1.56**	**0.89**

** Density -- woodland numbers per square km.*

Woodland distributions in the Yorkton Creek, Lower Assiniboine and Lower Whitesand watersheds exhibit similarities. Historically, these watersheds have been characterized by a low percentage of woodland area, a small mean woodland size, a large number of woodlands, and thus a high density. Over the period in question the percentage loss of woodland area and number is near or above the Basin average with all three watersheds experiencing an increase in average woodland size. The reduction of woodland area and number translate into a significant reduction of woodland density. This trend toward lowered densities and increased average woodland size would indicate that whole-scale removal of smaller woodland features is the dominant change mechanism in these watersheds.

The Lake of the Prairies watershed exhibits elements of both trends previously discussed. Historically, this watershed had the largest area of woodland with a woodland percentage and a mean feature size considerably higher than the Basin average. Over the period in question this watershed lost over half of its woodlands, but only experienced a small reduction of woodland area. Over the same period, average woodland size more than doubled accompanied by a drastic reduction of woodland density. This indicates the whole-scale removal of smaller woodlands with a few large tracts of woodlands on the southern slopes of the Duck Mountains and steep valley slopes remaining.

In general terms, watersheds that were primarily forested (Upper Assiniboine and Upper Whitesand) exhibit different change characteristics than watersheds that were historically more heterogenous. Essentially, physiography has dictated how agricultural development has occurred with encroachment and fragmentation characterizing the more forested watersheds and whole-scale removal of small woodlands dominating the other watersheds. Regardless of the process, the end result is a significant reduction of woodland area, number, and density for the entire Basin. These changes have altered the abundance, distribution, and pattern of woodlands and may have significant implications for ecological and hydrological functions associated with these areas.

The NTS map data are not the ideal basis on which to conduct change detection analysis of woodland features. However, in spite of the inherent weakness, trends illustrated in this analysis are dramatic and clearly indicate that significant alteration to woodland has occurred in all areas of the Basin. It is clear that some of the increase of improved land evident in the historical agricultural census can be accounted for by changes identified in the NTS map woodland features. However, the data used for this analysis only allow the comparison of woodland features and lack the thematic detail required to identify what land use now occupies areas previously known to be woodland. These data do not allow measurement of changes occurring on wetlands or native grasslands; this information is required to fully understand the hydrological and ecological consequences of agricultural expansion.

5.4 Water and Wetlands

5.4.1 Data Sources

Two sets of wetland data compiled from Landsat satellite imagery were available to the Committee. One data source was provided by the Prairie Farm Rehabilitation Administration (PFRA), developed as part of the Western Grains Transition Payment Program (WGTPP), and the other was prepared by Ducks Unlimited (DU) as a component of their habitat inventory databasess. The two sets were derived at different times of the year and had different purposes and intents. There were also differences on how the data were configured and compiled. Each has its advantages and limitations. Following is a brief summary of the basic characteristics of each data set.

WGTPP Data

- The focus was to categorize and quantify agricultural lands. The rationale for the classification scheme was to distinguish cropland and forage cover types from other non-agricultural uses. All quarter sections that had submitted claims under WGTPP were cross-tabulated with other available sources of land use information such as crop insurance and assessment data. The database provides a reliable snapshot of the land use during this period.

- For the Study area, images were acquired during late June or fall (September/October) of 1994 and 1995. Thus most temporary or ephemeral water had either soaked away or evaporated. These areas are then normally cultivated or utilized as pasture/haylands. This approach thus predominantly captures semipermanent and permanent wetlands only. Larger water bodies are generally more permanent than the more temporary wetland basins. Also, within the Basin, the more temporary basins exceed the more permanent wetlands in number and density.

- This methodology omits nearly all temporary water bodies. Thus, it eliminates the opportunity to account for these basin types as potential storage areas.

- Wetlands are represented in the WGTPP data by one of two classes. These are Wetland Vegetation and Open Water. Contiguous areas of these cover classes form complexes.

Ducks Unlimited Data

- The focus of the DU effort was to account for all surface water in the spring season. The data provide a good representation of all types of spring surface water.

- The satellite image was taken in May 1994 and May 1996 in order to capture all surface water (for an average runoff year or higher). Often temporary or seasonal wetlands are later cultivated or utilized as pasture/haylands. The water normally soaks or evaporates very quickly, in particular, as the frost thaws.

- These data allow for the inclusion of all water bodies as potential spring storage areas. The pixel size is 30 X 30 metres. Very small wetlands (less than 1 acre) are easily missed because of potential 'masking' by vegetation cover. Open water is easily discerned.

- Each pixel that is labelled as 'water' is also categorized as a specific wetland type In total, seven wetland cover classes were used based on the Kantrund and Stewart classification. Thus within a wetland complex, there may be several wetland classes. It becomes very difficult to accumulate and analyse individual wetlands basin wide.

- The DU data set did not contain information on upland cover.

There were unresolvable technical problems in trying to integrate the DU database with the WGTPP data. The main issues revolved around the different time periods for which the images were captured and the differing definitions for various wetland classes. Thus, it was not possible to spatially 'subtract' the wetlands of the DU data from the 'upland' areas of the WGTPP data.

The DFCC decided to use the WGTPP database because of the absence of technical difficulties and the ease of application. The Committee recognized the limitations of the WGTPP data and the potential application of the DU data. DU and WGTPP data were developed for their specific applications and both worked well for their intended uses. The Committee recommends that DU and PFRA GIS and/or remote sensing staff confer to determine if it is possible to make the DU data usable for the potential wetland storage determination by hydrologists. This may require the development of standard definitions and methodologies that address the needs of both agencies and other potential users of the databases. Further, ground-truthing of both data sets in a number of field locations is suggested. This should occur as soon as possible after snowmelt. The data sets would be evaluated to determine the accuracy of representing potential storage during spring runoff.

5.4.2 Current Spatial Distribution

Change detection analysis for wetlands in the Basin by comparing two map series, as was done for the woodlands, was not feasible due to data limitations. The dynamic nature of wetlands combined with the multi-temporal compilation of the NTS, causes inconsistent feature definition of wetlands in both editions. However, the land cover inventory developed from Landsat TM imagery for the Western Grains Transition Payment Program provides accurate and consistent definition of 'current' wetland abundance and distribution within the limitations discussed in the previous section. With acquisition dates well after spring snowmelt, many of the seasonal wetlands were not captured in the database. Therefore, the WGTPP data are a good representation of permanent wetland features. For the purpose of this analysis the definition of a wetland is a contiguous area of open water and/or wetland vegetation delineated in the WGTPP classified land cover. The features included in this analysis range in size from the smallest feature captured by the imagery (1 pixel or .09 ha) to the largest waterbody in the Basin (Lake of the Prairies, approximately 5,300 ha).

Table 5.5 summarizes the wetland numbers and areas by watershed and for the entire Basin.

Table 5.5 - Wetland Features - Basin Summary

Watershed	Watershed Area (ha)	Wetland Number	Wetland Area (ha)	Basin Percentage	Mean Size (ha)	Wetland Density *
UPPER ASSINIBOINE	328,700	6,130	21,220	6.5%	3.46	1.86
UPPER WHITESAND	428,300	8,800	19,540	4.6%	2.22	2.05
LOWER WHITESAND	306,100	6,610	16,280	5.3%	2.46	2.16
LAKE OF THE PRAIRIES	490,200	21,430	45,020	9.2%	2.10	4.37
YORKTON CREEK	232,400	7,180	10,660	4.6%	1.48	3.09
LOWER ASSINIBOINE	328,500	10,020	12,670	3.9%	1.26	3.05
Basin Total	**2,114,200**	**60,170**	**125,390**	**5.9%**	**2.08**	**2.85**

** Density -- Wetland number per square kilometre.*

Initial investigation of wetland distribution for the entire Basin reveals that a large number of relatively small wetlands dominate the landscape. The 60,000 wetlands occupying 125,000 ha represents only six percent of the Basin's total land area. However, the large number of features combined with a small average feature size contributes to density values approaching three wetlands per square kilometre for the entire Basin.

Table 5.6 provides an indication of the wetland distribution among the six watersheds both in terms of wetland area and numbers of wetlands.

Table 5.6 - Wetland Features - Distribution

Watershed	Wetland Number	Wetland Area (ha)	Percentage of Basin Total (Number)	Percentage of Basin Total (Area)
UPPER ASSINIBOINE	6,130	21,220	10.2%	16.9%
UPPER WHITESAND	8,800	19,540	14.6%	15.6%
LOWER WHITESAND	6,610	16,280	11.0%	13.0%
LAKE OF THE PRAIRIES	21,430	45,020	35.6%	35.9%
YORKTON CREEK	7,180	10,660	11.9%	8.5%
LOWER ASSINIBOINE	10,020	12,670	16.7%	10.1%
Basin Total	**60,170**	**125,390**	**100.0%**	**100.0%**

The watersheds with the largest number of wetland features are the Lower Assiniboine and Lake of the Prairies. Collectively these two watersheds account for 52 percent of wetland features in the Basin with the other watersheds equally accounting for the remainder. By area, the Lake of the Prairies watershed represents 36 percent of the Basin's wetland area (33 percent if the 5,300 ha of Lake of the Prairies is not included). The sheer number of small features in this watershed constitutes a significant proportion of the entire Basin's wetland features and area. Furthermore, if larger water bodies (Good Spirit Lake, Childs Lake, Fishing Lake, etc.,) are ignored, the remaining percentage of total wetland area is (approximately) distributed equally among the other five watersheds.

In general terms, the southern watersheds of the Basin are characterized by a greater proportion of small wetland features. Lake of the Prairies, Yorkton Creek, and the Lower Assiniboine watersheds all have high feature numbers, high densities and small average wetland sizes when compared to the other watersheds and the overall Basin average. Conversely, the northern watersheds (Upper Assiniboine, Upper Whitesand and Lower Whitesand) have lower wetland densities and greater average feature sizes when compared to southern watersheds and the Basin average. The occurrence of large water bodies (Good Spirit Lake, Newburn Lake and Fishing Lake) in these watersheds may partially account for larger average wetland size, however they have no impact on density measures.

In summary, some general wetland trends become obvious when examining the WGTPP data. Basin wide and in all watersheds, the average size of wetland features is small even in watersheds containing large water bodies. Furthermore, even with the large number of wetlands these features still constitute a low percentage of total Basin area. Southern watersheds tend to have a greater proportion of wetlands, smaller average size and higher feature densities than the northern watersheds, with Lake of the Prairies watershed typical of this trend. However, with the exception of Lake of the Prairies watershed, the difference between watersheds is minor, with all watersheds near the Basin average in terms of size and density parameters. Lake of the Prairies watershed contains a significant proportion of wetland numbers and area for the Basin, with wetland densities 50 percent higher than the Basin average. However, it should be noted that

these statistics represent average conditions for large watersheds and wetland density measures that exceed even the Lake of the Prairies watershed average occur locally.

5.4.3 Trend Analysis in Spatial Distribution at Sample Sites

In addition to the analysis based on WGTPP data presented above, three studies of wetland distribution and change over time have been conducted in portions of the Basin, two by DU and one by Sask Water.

The DU studies were 'in-house' evaluations of wetland losses and impacts of drainage on wetlands.

5.4.3.1 1995 Ducks Unlimited Analysis

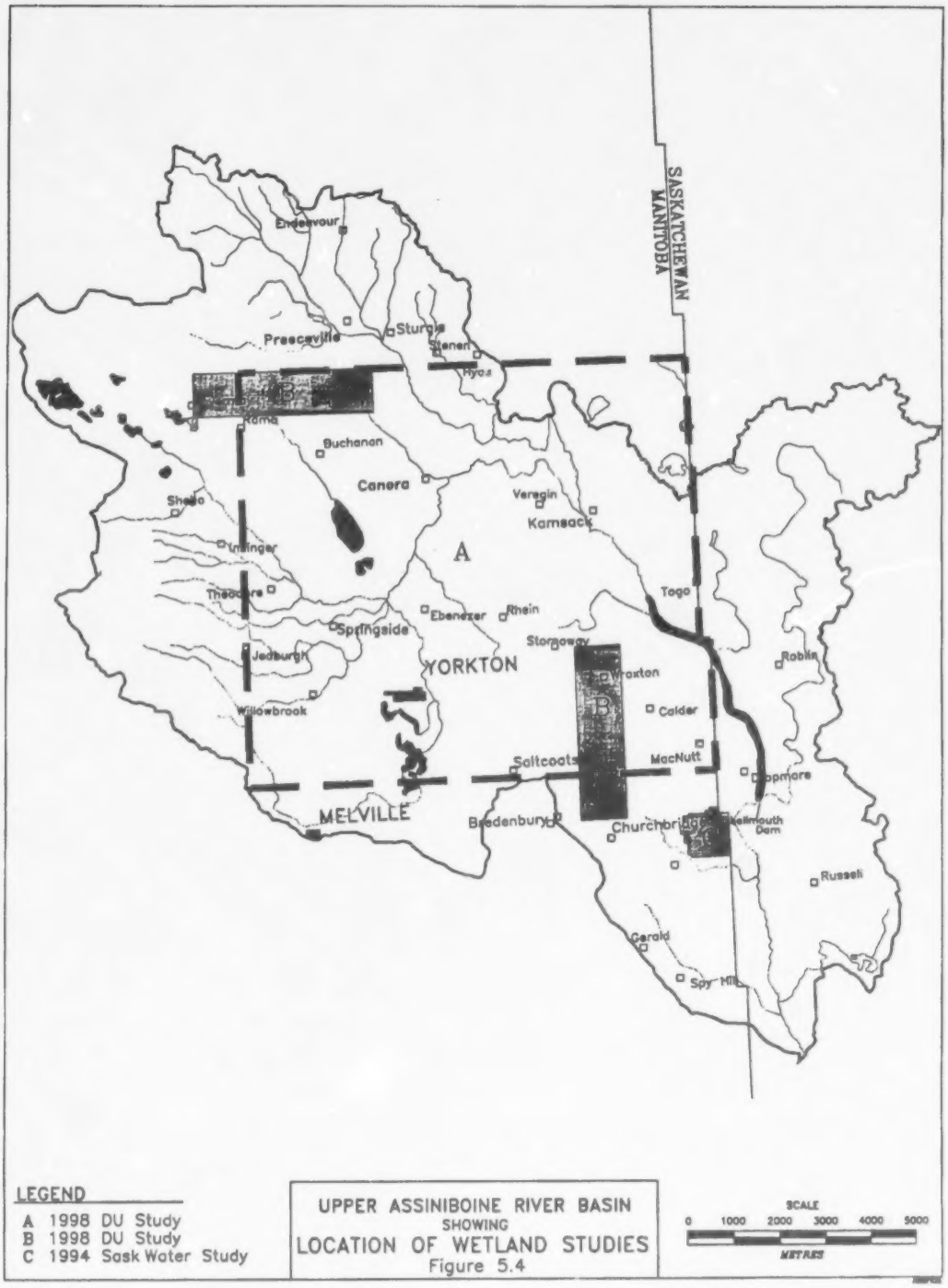
During the winter of 1995, DU staff located at the Yorkton office conducted a study in an attempt to document wetland loss that had occurred in the Yorkton region since 1949. The study area was 100 by 100 km with the south west corner of the block located 19 km south and 38 km west of Yorkton (see Figure 5.4). Twenty sections of land were randomly selected within the study area for investigation. To detect wetland changes aerial photographs of the selected sections from 1949 were examined to first estimate the wetland areas at that time. Then, for the same sections using aerial photographs from as recent as possible, wetland conditions were compared to determine if any drainage activities had occurred and to estimate wetland losses. Wetland areas on the target sections were also obtained using DU satellite imagery as a check for the most recent wetland area calculations.

This analysis was not intended as a scientific study but rather as a means to assess drainage activities in the Yorkton region and to compare the results to the value that is often cited in other literature. The results of the analysis were:

- The average percentage of wetland areas lost for the 20 sections was 45 percent;
- Eight sections had no wetland loss;
- Five sections had 100 percent loss; and
- Seven sections had some wetland loss.

The outcomes of this study compared favourably with the loss of wetlands on the prairies cited in other literature at about 45 percent. Wetlands are being drained for a number of reasons but it can be said that temporary basins (maximum depth less than 15 cm and normally dry by the end of May), seasonal basins (maximum depth > 15 cm, and normally maintain some surface water to mid-July), and semi-permanent basins (maximum depth > 1 m and normally maintain some surface water to freeze-up) are most likely to be affected first. This is because, in general, these wetland types are a function of topography. Another important issue is the proximity to an adequate outlet. The closer the wetland is to an outlet (natural stream or ditch), the easier it is to drain.

Figure 5.4
Locations of Wetlands Studies



5.4.3.2 1998 Ducks Unlimited Analysis

The autumn of 1997 was abnormally mild and dry in the Basin. This situation, coupled with the previous years of extremely wet conditions, motivated many producers to engage in extensive drainage efforts throughout the Basin. These undertakings were conducted by producers despite the Basin-wide drainage moratorium. DU was concerned with these activities and decided to hire a company to obtain black and white aerial photography in an attempt to record the drainage works that occurred in the fall of 1997.

The photography was done immediately after spring thaw of 1998, prior to the initiation of farm field work so that drainage efforts from the previous fall would still be evident. Ideally the entire Basin would have been photographed but the costs were prohibitive. Thus it was determined to photograph eight townships in two blocks of four townships each. One block was in an east-west alignment south-west of Buchanan and the other in a north-south alignment just north of Churchbridge (see Figure 5.4). These areas were chosen because they were anticipated to reveal intense drainage activities even though they were not necessarily representative of the whole Basin. Despite this likely bias, these townships are indicative of local areas in which wetlands are currently being impacted by agricultural development in the Basin.

A contractor was hired to interpret the photography over the autumn of 1998. The methodology was as follows:

- The analysis was applied to the 144 even numbered sections of land located within the eight townships.
- The 1998 photos were interpreted to identify all of the drainage works. This information was transposed onto 1949 photography (considered baseline information and is the oldest, wide scale aerial photography available for the watershed. Also, drainage activity prior to this was not considered to be wide spread).
- For each of the sections, the total area of wetlands that would have existed in 1949 was determined. The total area of wetlands that had been affected by drainage activities since 1949 was then calculated.
- Areas were recorded by section and then totalled by township.
- It was later decided to also document drainage activities that have occurred up to the mid-1980s (by reviewing aerial photography) to try to better quantify how much drainage had occurred within the last decade.

For the Churchbridge study area, the following was found:

- For the four townships, the percentage of affected wetland area from 1949 to 1998 ranged from 39 to 60 percent, with the average being 54 percent.
- For the comparison of 1980 to 1998 photography, the incremental alteration of wetland area ranged from eight percent to 21 percent with the average being 13 percent.

For the Buchanan study area, the results were:

- For the four townships, the percentage of affected wetland area from 1949 to 1998 ranged from 79 to 85 percent, with the average being 81 percent.
- For the comparison of 1980 and 1998 photography, the incremental alteration of wetland area ranged from nine percent to 18 percent with the average being 13 percent.

The overall change from 1949 to 1998 for the combined study area was 67 percent and the overall change from 1980 to 1998 was 13 percent.

The DFCC concluded from this study that most of the drainage activities had occurred prior to 1980, and that activities that were evident during the fall of 1997 was the maintenance and improvement of existing wetland drainage works in these already intensively drained study areas.

5.4.3.3 1994 Sask Water Analysis

In 1994 Sask Water prepared a project proposal for the Langenburg East Conservation and Development Area Authority. The drainage area of the project is essentially a single township (Tp 22 Rg 30 W1) and is located in the RM of Churchbridge (No. 211). As part of the overall study, air photos from 1957 and 1989 were utilized to determine land use information for the two time periods. Figures 5.5 and 5.6 depict graphically the results of the findings. These figures show that wetlands comprised 16 percent of the project area in 1957, and just under seven percent in 1989. This represents a 58 percent loss of wetland area over a period of 33 years.

Figure 5.5
Langenburg Land Use 1957

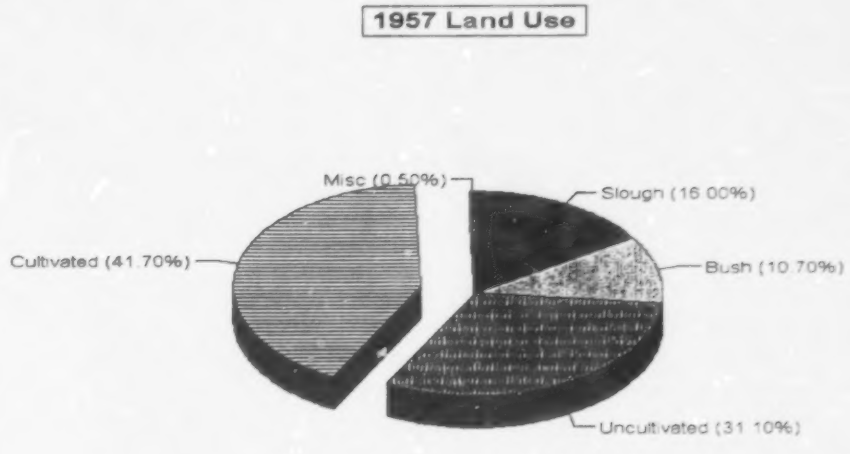
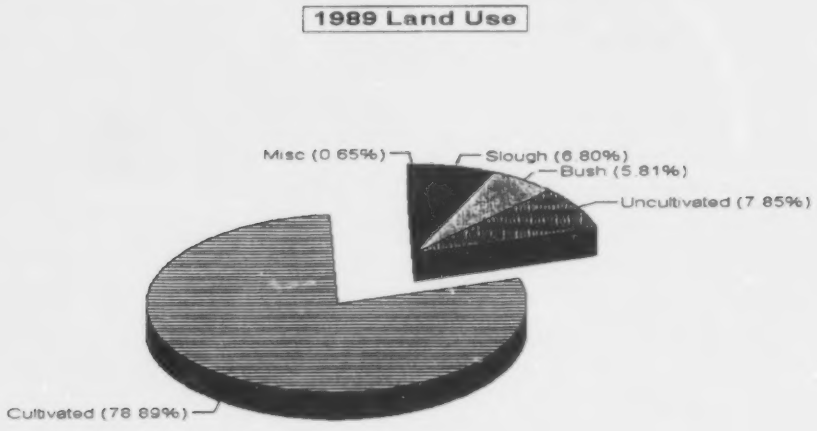


Figure 5.6
Langenburg Land Use 1989



5.4.4 Area-Volume Relationship for Prairie Wetlands

The WGTPP database provides a reasonably accurate evaluation of the current areal extent of wetland water surfaces. However, there is no readily apparent way to quantify the corresponding storage volumes contained within the wetlands for hydrologic analyses. To that end, work was undertaken to conduct a regression analysis of area-volume data for prairie wetlands in an attempt to develop a significant relationship between the surface areas and the corresponding storage volumes.

5.4.4.1 Study Data

Data for analysis were obtained from two sources: PFRA, and DU. Information on the two data sets is provided in Table 5.7. Data on the physical characteristics of the 81 DU wetland projects were initially obtained from project plans supplied by DU to Sask Water during the Water Rights approval process. Wetland projects selected for analysis were all from the Saskatchewan portion of the Basin.

PFRA project data sheets provided 105 sets of wetland information for analysis. After the initial examination of the data, nine sample sets were regarded as special cases since they were, in fact, a conglomeration of several wetlands. In order to maintain the integrity of the data, the data set was restricted to include individual wetlands only. Thus, although some regression analysis was carried out including the nine conglomerate wetlands, the 96 data points described in Table 5.7 encompass individual wetlands only.

Table 5.7 - Statistical Description of Wetland Data Provided by PFRA and DU

	PFRA Data Sample Size (n) = 96		Ducks Unlimited Data Sample Size (n) = 81	
	Area (ha)	Volume (dam^3)	Area (ha)	Volume (dam^3)
Mean	0.76	2.27	77.1	571
Median	0.32	0.68	32.6	171
Std. Deviation	1.4	5.47	106	924
Minimum	0.05	0.06	1.25	8.79
Maximum	10.1	41.6	493	4940

In all cases, DU and PFRA data, the areas and storage volumes provided represent full storage level (FSL) conditions. It is evident from Table 5.7 that both data sets are highly skewed. Although the PFRA data encompass wetlands up to 10 ha in area, more than 90 percent of the data are for wetlands under four hectares. Wetlands represented by DU data cover a much wider range with surface areas up to almost 500 ha. However, approximately 90 percent of the DU observations represent wetland areas under 150 ha while almost 50 percent are for areas under 40 ha. The difference in the makeup of the two data sets is likely due to a bias depending on the agency interest. DU has a greater interest in larger water bodies for the purpose of waterfowl habitat enhancement. On the other hand, the PFRA data is a result of applications by farmers who wish to enhance their farming operation by draining and developing controlled backflood projects in small wetlands on their land.

5.4.4.2 Analysis and Conclusions

A series of regression analyses was carried out with various groupings of the two data sets. The results of the regression analyses are presented in Tables 5.8 and 5.9, which, in addition to the central tendency of the areas and volumes of the sample wetlands, also provides the resulting regression equation, the coefficient of determination, and the standard error of estimate. Table 5.8 tabulates the results of the analyses for combinations of data sets with surface areas under 10 ha, while Table 5.9 shows the results for combinations of all wetlands. F-tests indicated that all regression analyses were favourable, well above the five percent level of significance.

The objective was to derive a regression formula that could convert wetland areas into corresponding storage volumes. Although a single formula would have been preferable an initial inspection of the two data sets indicated that a combination of two formulae might be required, one for smaller wetlands and one for larger ones. In addition to the obvious difference in wetland area between the two data sets, another factor came into play. During the process of analyzing the WGTPP satellite imagery for the Study, it was determined that approximately 95

percent of the wetlands in the Basin were under 10 ha in area. Thus the analysis looked first at just wetlands under 10 ha and then at all wetland sizes. The results are summarized in Tables 5.8 and 5.9.

As seen in both tables, the results indicate a reasonably strong relationship between the surface area and storage volume for all combinations of the data sets analyzed. In the under 10 ha category, the best results were obtained for PFRA wetlands under four ha in area (Table 5.8, lines 1 and 2). However, the inclusion of DU data for wetlands up to 10 ha (Table 5.8, lines 8 and 9) increased the applicability of the relationship to the desired 10 ha level at the minor cost of a slight decrease in the coefficient of determination and an increase in the standard error. Thus, the relationship for the log-log analysis of the combined data sets under 10 ha (Table 5.8, number 9) was selected as the formula of choice for use in the Study.

The analysis of data which included the larger water bodies, above the 10 ha level, had a detrimental effect on the resulting area-volume relationships, as seen in Table 5.9, with much lower coefficients of determination and excessively high standard error values. The best of the four tests was the result of the analysis using all the data from both data sets (Table 5.9, line 1). A relationship that explains 70 percent of the variance was considered quite acceptable, however a confidence band of 381 ha was significant, two orders of magnitude greater than the 1.75 ha standard error for the under 10 ha wetlands. Notwithstanding the poorer results, the fact that only 5 percent of the Basin wetlands are greater than 10 ha in area made the formula shown as Table 5.9, line1, the selected formula for application to the larger wetlands.

On inspection of the two selected regression formulae it was noted that at the 10 ha division point there is a rather large discontinuity. The under 10 ha formula gives a volume of 47.2 dam^3 for a 10 ha surface area, while the formula for larger water bodies gives a volume of 81 dam^3. The straight application of the two formulae would mean that there would be a sudden upward shift of approximately 34 dam^3 as one moved from a wetland area of 10 ha to one of 10.1 ha. To develop a smooth transition between the two formulae, it was decided that, since the under 10 ha formula was the more reliable of the two and that relationship was curvilinear, with a concave up configuration, it was extended beyond 10 ha until it met the linear relationship for the over 10 ha areas. The two relationships were found to converge at 70 ha. Thus, application of the under 10 ha formula beyond the 10 ha point would result in a diminishing difference in the volume discrepancy with increasing wetland area the closer the surface area got to the 70 ha point of convergence. That fact plus the point made earlier that only 5 percent of the Basin wetlands have a surface area in excess of 10 ha led to the acceptance of the transition solution just described. A graphical representation of the combined relationship is shown in Figure 5.7.

Table 5.8 - Results for Small Wetlands (Under 10 ha)

Description (Note: all regression analyses above the 5% level of significance)	Sample Size (n)	Area (ha)		Volume (dam^3)		Regression Equation	Coefficient of Determination (r^2)	Standard Error (SE) (dam^3)
		Average	Std Dev	Average	Std Dev			
(1) PFRA Project Data - wetlands under 4 ha *	93	0.55	0.67	1.47	2.09	$V = 2.85 A$	0.9	0.65
(2) PFRA Project Data - wetlands under 4 ha - as (1) but without ordinate constraint	93	0.55	0.67	1.47	2.09	$V = 2.97 A - 0.16$	0.91	0.65
(3) PFRA Project Data - Log-Log analysis of wetlands under 4 ha	93	0.55	0.67	1.47	2.09	$V = 2.43 A^{1.11}$	0.79	1.72
(4) DU and PFRA Data - wetlands under 4 ha	96	0.59	0.69	1.79	2.77	$V = 3.54 A - 0.29$	0.79	1.29
(5) PFRA Project Data - Individual wetlands under 10 ha *	96	0.76	1.4	2.27	5.47	$V = 3.43 A$	0.82	2.31
(6) PFRA Project Data - As in (5) but without ordinate constraint	96	0.76	1.4	2.27	5.47	$V = 3.56 A - 0.44$	0.82	2.29
(7) PFRA Project Data - includes 9 composite wetlands *	105	0.97	1.66	2.99	6.74	$V = 3.46 A$	0.78	3.2
(8) DU and PFRA Data - wetlands under 10 ha **	106	1.2	2.05	5.89	15.6	$V = 6.82 A - 2.31$	0.81	6.91
(9) DU and PFRA Data - Log-Log analyses - wetlands under 10 ha **	106	1.2	2.05	5.89	15.6	$V = 2.85 A^{1.22}$	0.88	1.75

* Regression intercept forced to the origin

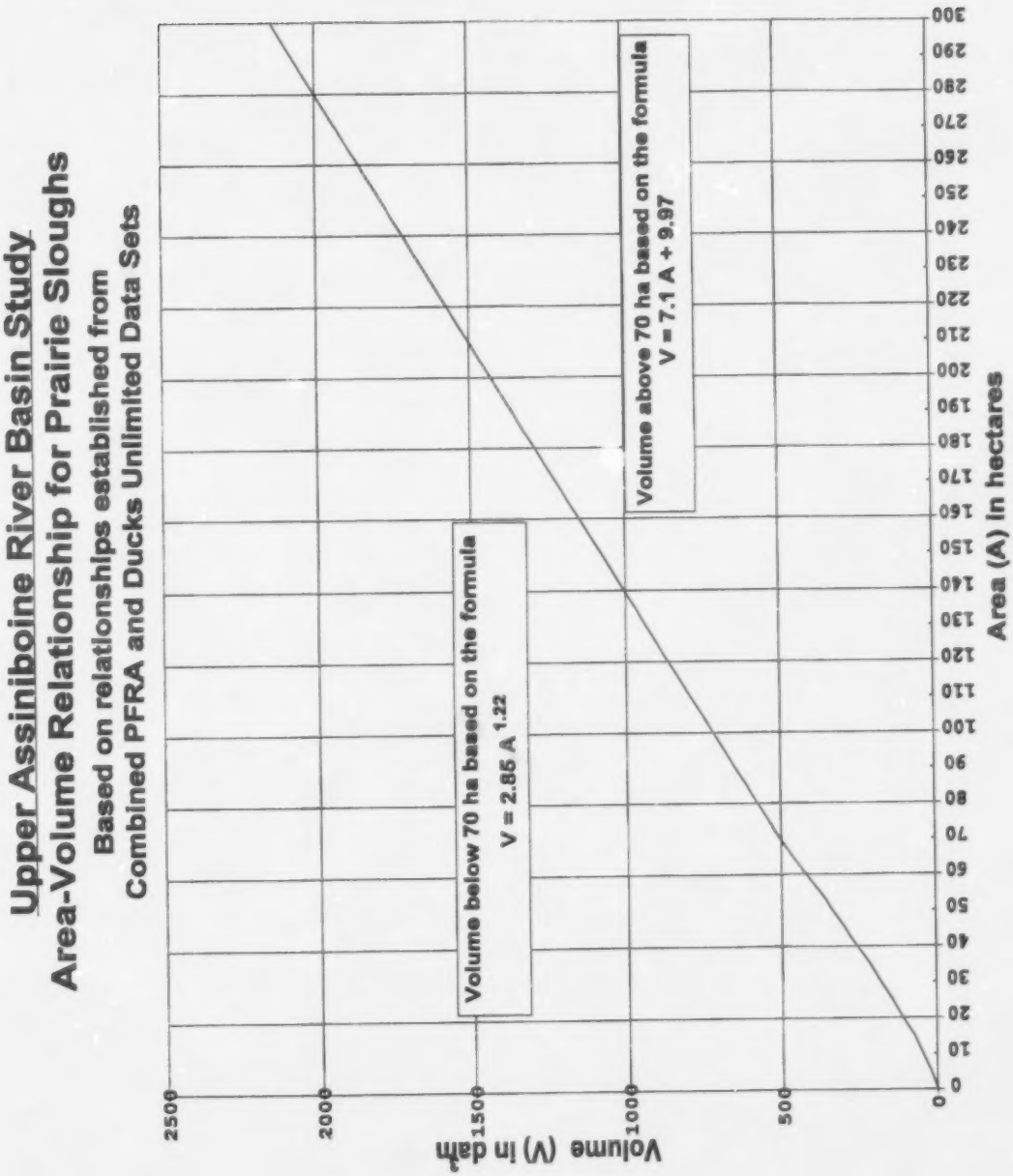
** PFRA data for individual wetlands only (i.e., no composite wetlands included)

Table 5.9 - Results for Large and Small Wetlands

Description (Note: all regression analyses above the 5% level of significance)	Sample Size (n)	Area (ha)		Volume (dam^3)		Regression Equation	Coefficient of Determination (r^2)	Standard Error (SE) (dam^3)
		Average	Std Dev	Average	Std Dev			
(1) DU and PFRA Data - All sizes **	177	35.7	80.9	262	686	V = 7.1 A + 9.97	0.7	381
(2) DU Data	81	77.1	106	571	924	V = 7.0 A + 33.6	0.63	567
(3) DU and PFRA Data - wetlands over 4 ha **	81	77.3	105	571	924	V = 6.97 A +32.4	0.63	567
(4) DU Data - wetlands over 10 ha	71	87.2	109	645	964	V = 6.94 A + 40.6	0.62	606

** PFRA data for individual wetlands only (i.e., no composite wetlands included)

Figure 5.7
Area-Volume Relationship for Prairie Wetlands



Thus, it was found that the formulae shown below give a reasonable estimate of wetland storage volume based on the surface area of the wetland in the Basin.

(1) For surface areas of wetlands up to 70 ha:

$$V = 2.85\ A^{1.22}$$

(2) For surface areas of wetlands greater than 70 ha:

$$V = 7.1\ A + 9.97$$

Where: **A** = wetland area in hectares (ha)
V = Storage Volume of wetland in decameters squared (dam^3)

5.4.4.3 Comparison with a Previous Study

A 1967 paper by Haan and Johnson entitled *Geometrical Properties of Depressions in North-Central Iowa* describes a similar attempt to relate the surface areas of wetlands to their corresponding storage volumes. Although there is no intent to verify or deny the results of this Study on the basis of the results of the Iowa study, it is of interest to compare the results of the 1967 study with those from this Study. It is recognized that differences in surface soil type, grain size distribution, and cohesiveness, can exert a considerable influence on the slope, depth, and storage volume of the wetland depressions despite the similarities in the geological history of the two areas.

The State of Iowa was subjected to glaciation to a similar extent and degree as the Canadian Prairies. In parts of the State there are expansive glacial outwash plains dotted with wetland depressions, much like vast areas of the Canadian Prairies. It is conceivable, therefore, that a similar relationship might exist between surface areas and volumes of the wetlands of Iowa and those of the Canadian Prairie region. Two data sets were analyzed during the Iowa study, one for an area known as East Fork Hardin Creek and the other for an area called Emmit Creek. Table 5.10 compares the sample characteristics and analysis results for the two Iowa State data sets. For comparison purposes Table 5.10 also contains the data characteristics and analysis results for the accepted data set for wetlands under 10 ha from this study, that being analysis number 9 from Table 5.8. It was decided to restrict this comparison to the under 10 ha analysis and exclude that for the over 10 ha area wetlands since the two Iowa data sets were from a similar surface area sample to that of the data set used in the accepted, under 10 ha analysis.

One of the first observations from Table 5.10 is that, although the averages of the surface areas are similar in size, the average volumes for the Iowa data set are around half that for the Canadian counterpart. Also, while the coefficients of determination are very close, the standard error values resulting from the Iowa analyses are five to seven times lower than the corresponding value resulting from this analysis.

To examine the possible link between the three relationships, a series of volumes was generated for each of the three formulae for a common set of surface area values. The surface area values began at two ha and extended to 30 ha in two ha increments. A graphical comparison of the relationships is provided in Figure 5.8, which shows that the three relationships are quite divergent, as one might expect from the exponential differences in the three formulae. Although the regression analyses are only valid for low values of wetland surface area, the graphical representations were extended to the 30 ha level to adequately illustrate the nature of the divergent curves. A Student's t-Test of the statistical significance of the possible relationship between the current relationship and either of the Iowa relationships was carried out with the volume values generated from the respective formulae. The results of the t-Tests indicate that there is a very high probability, better than 99.99 percent chance, that the volumes developed in this Study are from the same population as those developed from the East Fork Hardin Creek formula. However, there is a reduced chance, approximately a 95 percent probability, that the volumes from this Study and those from the Emmit Creek study are from the same population.

Figure 5.8
Comparison of Wetland Area-Volume Relationship Results

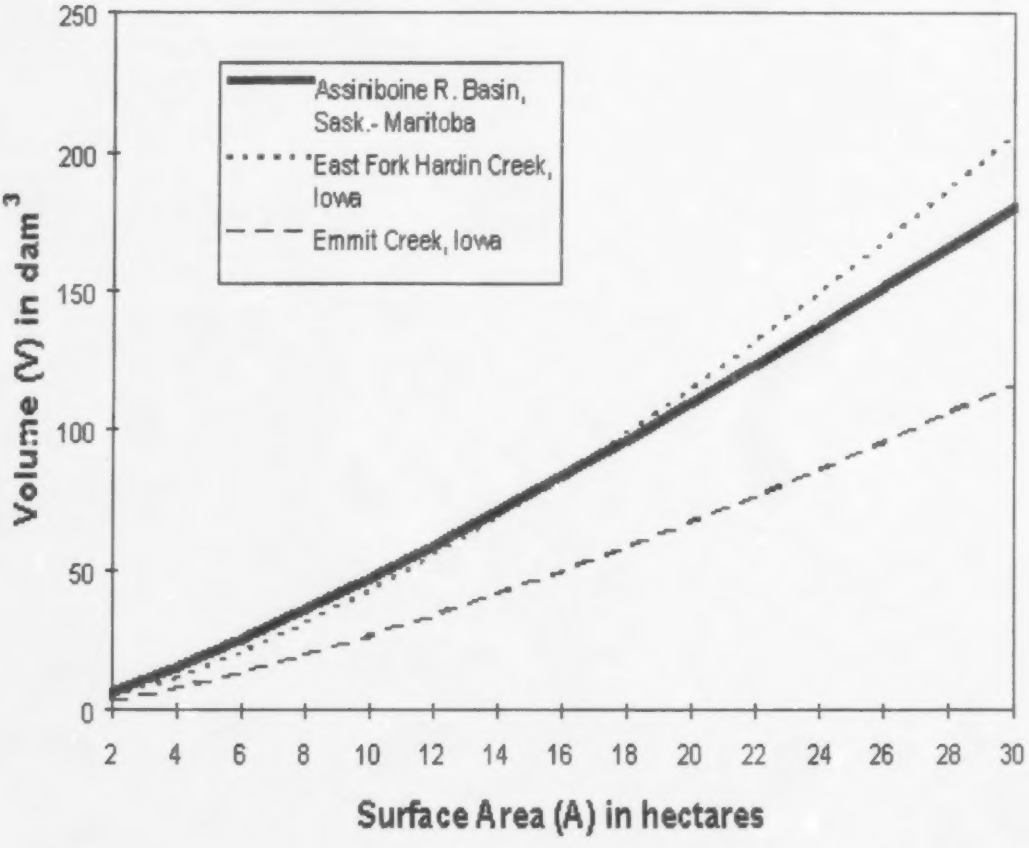


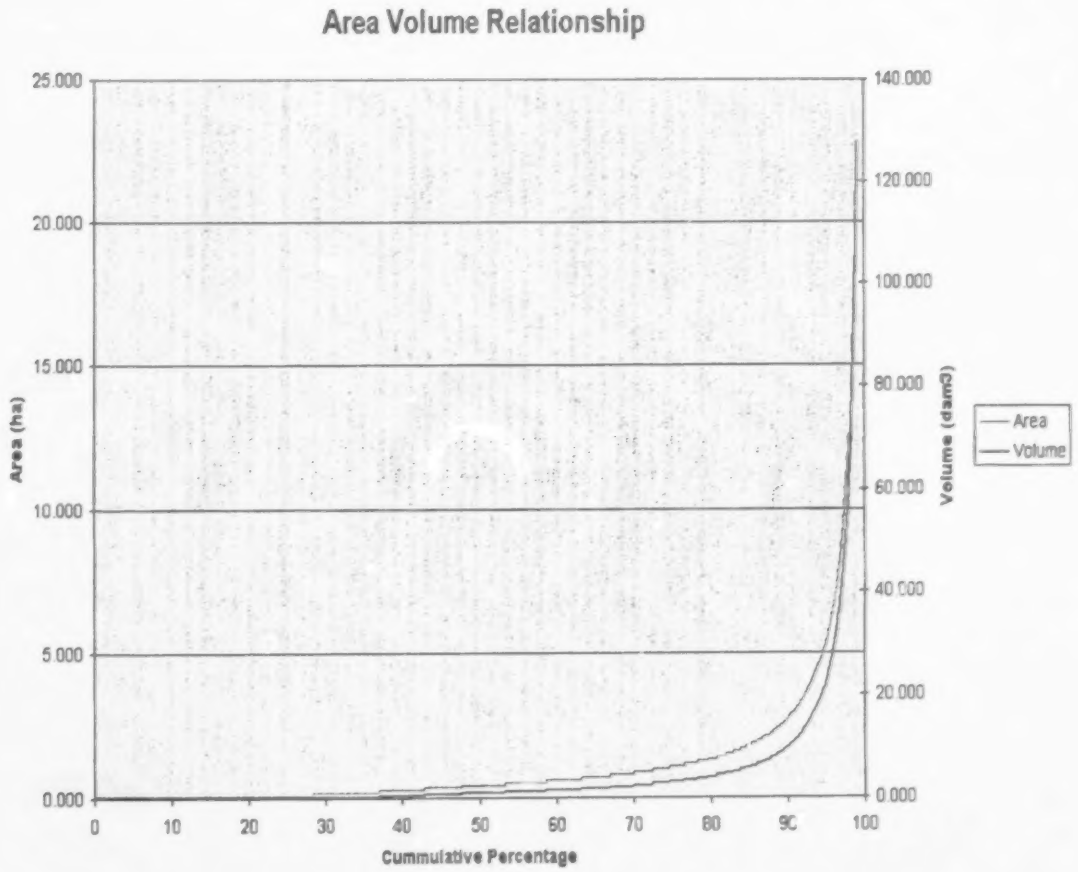
Table 5.10 - Comparison Between the Accepted Results for Small Wetlands and the Results of the 1967 Iowa Study

Description (Note: all regression analyses above the 5% level of significance)	Sample Size (n)	Area (ha)		Volume (dam^3)		Regression Equation	Coefficient of Determination (r^2)	Standard Error (SE) (dam^3)
		Average	Std Dev	Average	Std Dev			
Results for Small wetlands Combined DU and PFRA data (wetlands under 10 ha)	106	1.20	2.05	5.89	15.60	$V = 2.85\ A^{1.22}$	0.88	1.75
East Fork Hardin Creek 1967 Iowa Study	70	0.927	2.04	2.52	9.00	$V = 1.54\ A^{1.44}$	0.92	0.23
Emmit Creek 1967 Iowa Study	232	1.25	3.06	2.89	7.48	$V = 1.14\ A^{1.36}$	0.89	0.34

5.4.4.4 Application to Basin

The area-volume relationship was applied to all wetlands under 400 ha in surface area in the WGTPP database. This exercise indicated that these wetlands have a total surface area of about 25,500 ha and an estimated potential total storage volume of 130,000 dam^3. Figure 5.9 shows the cumulative area and cumulative storage volume of these wetlands as a function of the number of wetlands. The figure shows that 80 percent of the wetlands comprise about 10 percent of the wetland area and 90 percent of the wetlands comprise about 10 percent of the Basin wetland volume. Put another way, the largest 20 percent of Basin wetlands in the WGTPP database comprise 90 percent of the wetland area and the largest 10 percent comprise 90 percent of the wetland volume of water bodies under 400 ha.

Figure 5.9
Cumulative Basin Wetland Area and Volume



It is recognized that in using the WGTPP database, there is a bias to underestimating the Basin wetland surface area, and hence volume, since most ephemeral and temporary wetlands were not captured in this database as discussed in Section 5.4.1.

The area-volume relationship could not be applied to the DU wetland database as that database may assign several wetland categories to the same complex, whereas the area-volume relationship was developed to be applied to the wetland complex. Even if the DU database wetlands were compatible, the relationship may not be valid for temporary and ephemeral wetlands as these were not used in developing the relationship.

The wetland storage potential indicated above is small relative to flood runoff volumes in the Basin. Runoff volumes have exceeded 130,000 dam^3 in all but four years in the 55-year period 1941-95, and the median annual runoff volume of 345,000 dam^3 is 2.65 times the wetland storage potential. The potential wetland storage volume is an even smaller portion of the total runoff volumes in flood years as can be seen on Figure 2.7. Consequently, at the Basin scale and considering the likely underestimation of potential wetland storage, even if all the wetlands were completely dry prior to runoff, natural storage in wetlands would not significantly impact streamflows in large flood events.

Consequently, drainage of the smaller wetlands represented in the WGTPP database would not significantly reduce the wetland storage potential in the Basin determined using the WGTPP database. While drainage of smaller wetlands may not have a significant impact at the Basin scale, there may be more significant effects at the local level and on a watershed scale. Also, as discussed in Section 3.5.3, the wetland storage upstream of the lake is an important element in Manitoba's flood management, and loss of a significant portion of that upstream storage could have implications on the management of Lake of the Prairies for flood control.

5.5 Summary

The material presented in this chapter shows that the Basin has undergone tremendous changes in land use since settlement times. There are at least three simultaneous dynamic processes occurring in the Basin with respect to changes in the landscape.

- Over the past 40 years, the amount of land used for agricultural production has increased substantially. Another ongoing trend within the land classed as "improved" is the decreasing proportion of land which is summer fallowed. The increasing proportion of land left in stubble overwinter may be an important factor in spring runoff rates. The increase in "improved" land use area has been derived from reductions in the area of "un-improved" lands, which includes woodlands and wetlands.

- Significant reduction in woodland has occurred in all areas of the Basin both in terms of the number of woodland areas and the total area of woodland in the Basin.

- Significant alteration to wetland areas has occurred in at least some portions of the Basin both in terms of numbers of wetlands and the total area of wetlands in the Basin.

Wetland distribution, both in terms their spatial distribution through the Basin and in terms of their size distribution was examined in this chapter.

- An examination of wetland sizes and numbers in the mid-1990s reveals that the average wetland size is quite small. Despite the large numbers of wetlands throughout the Basin, they constitute a relatively small portion of the total Basin area as detected by the WGTPP satellite images.

- Previous studies of intensively drained areas in which time series of air photos were examined suggest that wetland loss has been substantial.

- Wetland storage potential based on the WGTPP database is small relative to the volume of major floods in the Basin.

- A wetland area-volume relationship was developed for use in conjunction with data sets of wetland area to in order to determine wetland storage volumes in the Basin.

- Collection of additional field data for seasonal and temporary wetlands in the Basin is required to give greater confidence in applying the area-volume relationship in the range of wetlands subject to contour ditching and V-ditching.

- Water and wetland management agencies need to work together to define common standards and definitions in the assembly of wetland databases.

6 Effects of Land Cover Change and Drainage on Runoff

A number of methods are available to assess both the effect of drainage on the hydrology of a watershed, and the effect of land cover change on a watershed. These methods have been grouped into five areas of discussion. Each is described and assessed for its applicability to the Basin in the five following sections.

6.1 Effects of Land Cover Changes and Agricultural Practices

Most of the runoff in Saskatchewan occurs during spring, as a result of snowmelt (Price, 1993; Maule and Gray, 1994; Van Der Kamp *et al.*, 1999). Maule and Gray (1994) indicate that in southern Alberta and Saskatchewan, more than 85 percent of the annual runoff is derived from snowmelt. Figure 2.6, described earlier, depicts that for a small stream in the Basin snowmelt runoff makes up 90 percent of the annual runoff. Runoff produced from a summer rainstorm is typically very localized and is usually not significant for the Basin as a whole.

Research into the hydrology of prairie streams has found that runoff occurs during snowmelt primarily because of the reduced infiltration capacity of the soil while it is frozen (Gray *et al.*, 1985; Byrne, 1989). The accumulation of precipitation over four to six months as the winter snowpack followed by its release over a relatively short melt period results in the melt rate (mm/day) exceeding the infiltration rate of the soil. The excess melt then becomes the surface runoff, either to be stored in wetlands or other water bodies, or to flow into the stream network.

It is important to note that the largest land use component within the Basin is annual cropland. Census Canada statistics show that the 'improved area' has been rising steadily since 1956. As discussed in Section 5.2, the latest statistics indicate a levelling off of any additional area within this improved category (76 percent for the entire Basin). Thus, farming practices on these improved areas have the potential to influence the hydrology of the watershed.

6.1.1 Physical Processes

The physical processes by which land cover and agricultural practices can affect the snowmelt runoff from a watershed have been the subject of extensive research. One of the primary effects is the redistribution of snow by winds over the course of the winter. The following conclusions are summarized from the recent text "Snowcover: Accumulation, Relocation and Management" (Pomeroy and Gray, 1995):

- In open areas, wind may redistribute up to three-fourths of the annual snowfall.
- If the wind fetches are large, most of the transported snow sublimates in transit. For short fetches, most snow is deposited in drifts.

- Wind relocation of snow is extremely sensitive to surface roughness. Smooth surfaces such as fallow fields and ice become sources of blowing snow while rougher covers act as snow traps.

- Excess snow relocates to 'drift' areas of increasing surface roughness such as stubble fields, shelter belts, coulees and wetland margins. Thus, even though wetland margins, gullies and valleys may occupy a small percentage of the whole catchment, a large proportion of the blowing snow may accumulate there because of the sheltering effect of the cover. The areas of deeper snow take longer to melt, thereby increasing the runoff volume and extending the duration of runoff, but reducing the peak flow. The concentration of snow and resulting meltwater will saturate the runoff path and since these areas were also generally located close to the stream network, the melt water is then more likely to find its way into the streams.

- Wheat stubble in southern Saskatchewan reduces snow transport by half when compared to that on fallow fields. Stubble fills with snow, packs and refills. Fresh snow is trapped within standing stubble and is protected from the wind. This snow compacts and consolidates, in particular after mid winter thaws. The snow is reduced in depth but still contains the same amount of water. The consolidation of the snowpack permits the accumulation of fresh snow on top of the compacted snow within the standing stubble. Once the depth of snow exceeds the height of the stubble, the stubble field then becomes a source of blowing snow which is transported to cover with even greater roughness.

- Increasing stubble height and area of stubble field will reduce the snow available for redistribution into wetland margins, coulees, and valleys. This will tend to reduce overall runoff volumes from a watershed.

Some of the general findings on other physical processes are:

- Several sources comment on the insulative aspect of stubble and increased snow cover. The additional snowcover augments the insulation value which reduces the depth of frost penetration. This increases the infiltration capacity during snowmelt.

- Cover type has a strong influence on the porosity and structure of the underlying soil. For example, bush and shrubs will tend to have very high infiltration rates. Cultivated fields will have lower rates. Tillage practices also have an effect (e.g., minimum tillage versus summer fallow).

- Unworked stubble improves soil macropore structure over a period of years. This structure is further enhanced with the adoption of zero tillage. The improved macropore structure contributes to increased snowmelt infiltration during spring.

- Different land covers may affect the albedo (reflectance of incoming solar radiation), particularly as the snow cover thins and portions of the land surface become exposed. Bush and shrubs affect the amount of sunlight penetrating to the snow cover.

- Stubble and increased residues slow the movement of water across a field. The increased surface roughness coefficient results in increased cross sectional areas of flow which translates to decreased velocities and hence energy. Not only does this reduce soil erosion potential it extends the travel times for snowmelt to reach the watershed waterways.

6.1.2 Application to Producers

Saskatchewan Agriculture and Food encourages producers to retain crop stubble over winter. The following information was obtained from that department's fact sheet "General Moisture Conservation Techniques."

- The use of stubble to redistribute snow has been developed to enhance crop production on the prairies by increasing available spring soil moisture. Snow management on agricultural lands can increase the yield of spring wheat by more than 10 kg/ha per mm of additional snow water equivalent.

- Retaining stubble over winter has been a long accepted means of increasing spring soil moisture on the prairies. Saskatchewan Agriculture and Food studies have shown that undisturbed stubble 15 to 23 cm in height can conserve 13 to 25 mm more soil moisture than stubble which was cultivated in the fall.

- Tall stubble (30 cm high or more) coupled with straight combining traps snow more effectively and evenly. There are other practices such as alternate stubble heights or trap strips which further increase the effectiveness of catching snow in stubble. In years when the soil is dry at freeze up, conservation of up to 100 mm of water is possible.

- Direct seeding (minimum tillage) that has no fall tillage, with one high disturbance tillage just before spring seeding, normally conserves almost as much moisture as zero tillage practices.

6.1.3 Land Cover and Snowmelt Runoff Research

Land use and land cover may have a strong effect on snowmelt runoff rates from individual fields. Experimental data on the effect of land cover and agricultural practices are available on a field scale and on the scale of a small watershed.

Van Der Kamp *et al.* (1999) explains that adopting farming practices which represent a land use approaching 'natural or original' prairie conditions have the potential to reduce runoff. That study looked at 10 small wetlands located in the St. Denis Wildlife Area near Saskatoon. Wetland water levels had been recorded there for 30 years beginning in 1968. In the early 1980s the uplands of some of the wetlands were converted to permanent grass cover as nesting cover for wildlife. In the initial years after conversion higher runoff rates were observed than in the adjacent unconverted watersheds. However, after a few years, runoff rates from the converted

watersheds were substantially less than the in the unconverted watersheds. This had profound effects on the hydrologic balance of the wetlands. From 1987 onwards, wetlands in the grassed areas became much drier. In fact some wetlands dried up and remained dry even in years of heavy precipitation.

Van Der Kamp *et al.* were not able to identify the specific hydrologic processes that resulted in the profound change in runoff from the watershed which had been converted to permanent cover, however they do speculate that increased infiltration of snowmelt may be one factor. The DFCC concurs that this may indeed have been a factor in that after several years, a macropore structure may have developed in the converted watersheds which would lead to higher infiltration rates even under high snowmelt runoff conditions.

Maule and Gray (1994) used observed snowmelt runoff rates from fields in stubble/fallow rotation to calibrate a snowmelt runoff model for the Canadian Prairies. The observed runoff rates were taken from eight test stations over a period of several decades. One of their findings was that fallow fields generate less runoff than stubble fields. This was due to the stubble not having sufficiently developed a macropore structure to have a higher infiltration rate that would receive the increased snowmelt waters resulting from the higher snow trapping ability of the stubble. On a field scale, snow will tend to blow off the fallow field into the adjacent stubble field. On a watershed scale, this result may not be applicable since snow lost from a fallow field in one part of the watershed will accumulate on the adjacent stubble fields in the same watershed thus masking the effect of individual fields.

Thus, long-term stubble retention and/or conversion to permanent cover is likely to reduce overall runoff volumes and spring peak flow rates on a watershed basis.

6.1.4 Application in the Basin to Determine Potential Effects

The present trend on the prairies is towards conservation farming practices involving such measures as retention of stubble overwinter and fewer tillage operations. Runoff rates can be altered by this change in agricultural practices. Consider the following two figures, both derived from the 1996 Agriculture Canada Statistics (Table 5.1). In Figure 6.1 it was assumed that 25 percent of the annual cropland area is retained as stubble over winter and that the remaining cropland is 'fall worked.' All other covers remained as reported in the Table 5.1, including the summer fallow area. Thus, in this scenario nearly 51 percent of the Basin (worked and summer fallow) could be considered as possessing a higher runoff potential.

In the second scenario, shown in Figure 6.2, it is assumed that the summer fallow area is reduced by 50 percent (the other 50 percent is transferred to annual cropland). In addition it is assumed that 75 percent of the annual cropland is retained as stubble over winter and that the remaining cropland is 'fall worked'. All other covers remain as reported in Table 5.1, including the summer fallow area. In this scenario the higher runoff potential land cover is reduced from 51 percent to 20 percent of the Basin area.

Figure 6.1
Land Use Scenario for Higher Runoff Potential

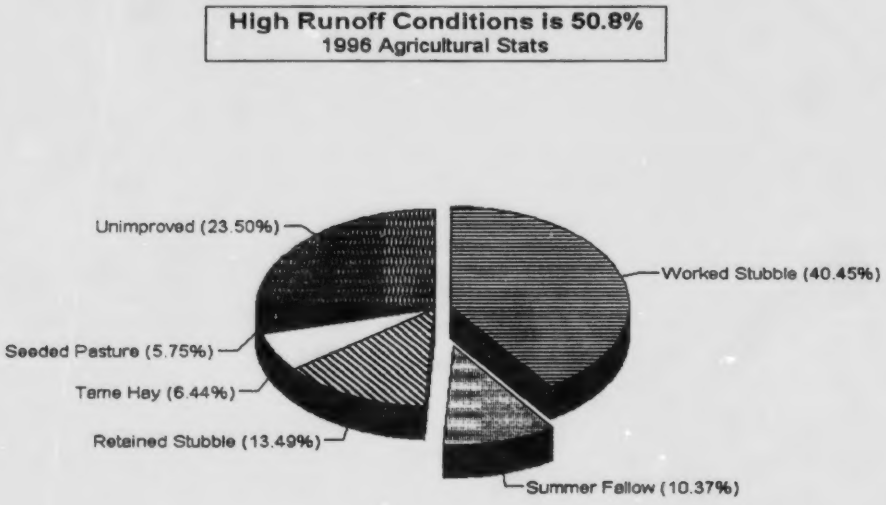
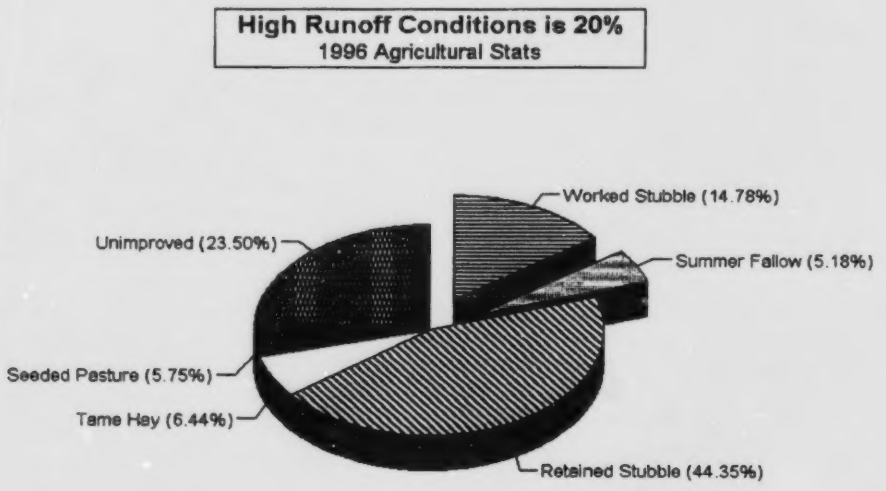


Figure 6.2
Land Use Scenario for a Lower Runoff Potential



The changes to the woodland area, and woodland size distribution discussed in Section 5.3 also have the potential to affect runoff in the Basin. The analysis in Section 5.3 found that many of the small isolated woodlands have been eliminated over the past several decades. This will tend to increase average wind fetch lengths. As discussed in Section 6.1.1, increased fetch lengths will result in the removal of more snow from open areas. Depending on the length of the fetch, this will result in either increased losses to sublimation of the snow in transit, or increased deposition of snow in the remaining woodlands and other "trap" areas. As many of the remaining woodlands in agricultural areas are located close to the stream network (i.e., valley walls and stream corridors), greater snow accumulations in these areas would result in increased runoff volumes over an extended duration. Without detailed assessment of changes in fetch lengths and the resulting impacts on snow transport, sublimation, accumulation, and melting, it is not possible to determine the effect of changes in woodland area and distribution on runoff in the Basin.

6.1.5 Summary

Pomeroy and Gray (1995) state that, "because snow accumulation can often be managed with subtle changes in the spatial distribution and geometry of vegetation or with modest engineering structures, snow management techniques present an opportunity to augment water supply at the surface without irrigation and to ameliorate excess runoff without dams or other water control structures". The premise is to utilize as much snowmelt as possible for agriculture by retaining snow cover on the fields and reducing runoff. Also, the use of stubble will store snow on the uplands away from gullies and valleys. Thus the flow paths are increased and the travel times are correspondingly lengthened. The net effect is to extend the hydrograph and lower the peaks.

The DFCC therefore recommends that agricultural best management practices such as zero till, permanent cover programs, and retaining or re-establishing native cover be promoted as means to reduce runoff rates and volumes. Permanent cover improves infiltration and slows the flow of water. The addition of permanent vegetative buffer strips along waterways would further augment the water quality of spring runoff, before it enters streams and other water bodies. Finally, the conversion of marginal lands from cultivation to permanent grass cover (as hay lands or pasture) would have similar benefits.

Unfortunately, there is limited scientific literature on the impact of land cover and agricultural practices on snow accumulation and snowmelt runoff on a larger scale in the Canadian Parkland region. Most research has focussed on row crops and rainfall events. The implications are that for predictive computer simulation models of snowmelt, it is difficult to model runoff events on a watershed scale.

The DFCC recommends research to verify that the effects of agricultural practices and land cover changes are applicable to small watersheds in the Basin. Specifically, the impact of long-term stubble retention or conversion to permanent cover should be studied for a watershed area greater than 15 km^2 using a twinned watershed approach.

6.2 Streamflow Analysis

6.2.1 Introduction

The drainage of wetlands, the clearing of trees and vegetation, development of road infrastructure, and alterations to land use practices all may have a significant effect on the hydrologic response of a watershed. The predominant land use in the Basin is cropland (54 percent based on Figure 5.2). Farming practices conducted on this cropland potentially may also have an impact on runoff as discussed in Section 6.1. Generally, as more wetlands are drained and native parkland cover is converted to cultivation (with clearing of bush and breaking of grasslands) the hydrologic response of the area will be increasingly altered. Runoff volumes will increase because of the overall elevated runoff coefficient of the watershed. As well, there may be an associated quickening of the response time of the runoff event. The resultant runoff hydrograph shape may be steepened and shortened with an increase in the peak discharge.

To determine if the changing land cover and land management practices in the Basin have had an impact, the existing hydrometric streamflow data in the Basin was analyzed using standard hydrologic techniques.

6.2.2 Analogue Years

Streamflow data for years with similar climatic conditions were compared to determine if a change could be detected in the runoff response within the Basin over time. Streamflow has been recorded on the Assiniboine River at Kamsack since 1944. Although the Assiniboine River near Russell has streamflow records dating back to 1913, the construction of Shellmouth Dam and the creation of Lake of the Prairies have influenced the records. Consequently, the Assiniboine River at Kamsack, which drains 61 percent of the Basin, was used for comparison of analogue years. The following information for Assiniboine River at Kamsack obtained from the Manitoba Flood Forecast Center for the period 1948 to 1999 was used to select analogue years:

- RO = Recorded spring runoff volume in mm over the 12,954 km^2 watershed.
- P = Winter and effective spring precipitation (mm) which could potentially contribute to runoff.
- MI = Melt Index (average degree days/day above –1° C).
- API = Antecedent Precipitation Index (mm) based on weighted May to October monthly precipitation.

The first analogue years compared were 1948 and 1997. These years both represent approximately 1 in 10 year flood events. The year 1948 typifies early development conditions in the Basin, whereas the year 1997 reflects current development. The API, P, MI, and RO for each year compared to the long term average are shown in Table 6.1.

Table 6.1 - Comparison of Assiniboine River at Kamsack for 1948 and 1997

Year	API (mm)	Winter Precipitation (mm)	Melt Index (°C)	Spring Yield (mm)
1948	120	210	5.9	23
1997	115	160	5.0	26
1948-1999 Average	110	132	6.9	12

As indicated in Table 6.1 the fall antecedent moisture condition for both years was slightly above the long-term average and was nearly identical for both years. The winter precipitation was well above the long-term average in both years with 1948 having 31 percent more winter precipitation than 1997. The Melt Index was slightly below normal in both years with 1948 having an 18 percent larger value than for 1997. The runoff hydrographs for 1948 and 1997 are shown on Figure 6.3

The rising limbs of the two hydrographs shown in Figure 6.3 are virtually the same. The expected results from this information would be a higher yield for 1948 than for 1997. However, the opposite occurred, with 1997 actually having a 13 percent higher yield than 1948. Also, the peak discharge for 1997 was about 10 percent higher than for 1948. In addition, the peak flow in 1997 occurred five days earlier and the recession limb of the hydrograph was flatter. These hydrograph characteristics are consistent with expectations given the known changes to the landscape.

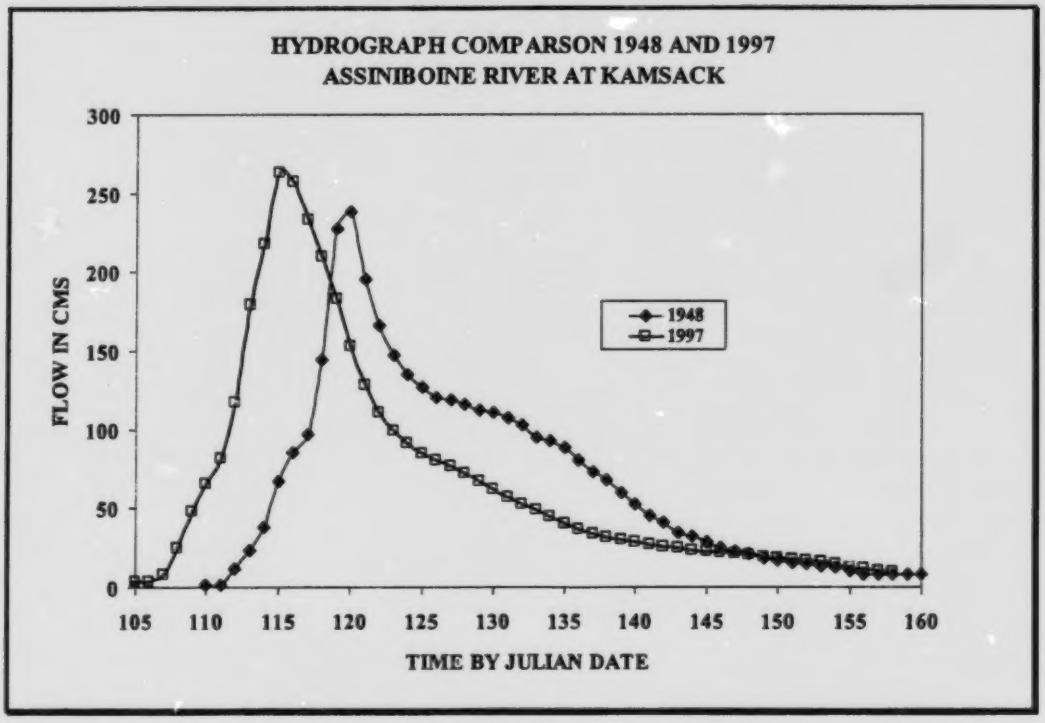
The second analogue utilized the years 1971 and 1985 as parallel years. These years correspond hydrologically about 1 in 5 year flood events. The API, P, MI, and RO for 1971 and 1985 are shown in Table 6.2.

Table 6.2 - Comparison of Assiniboine River at Kamsack for 1971 and 1985

Year	API (mm)	Winter Precipitation (mm)	Melt Index (°C)	Spring Yield (mm)
1971	140	124	10.9	17
1985	140	125	9.0	22
1948-1999 Average	110	132	6.9	12

As indicated in Table 6.2 the fall antecedent moisture condition was identical for both years and was well above average. The winter precipitation was nearly identical and slightly below the long term average. The Melt Index was well above normal in both years. It should be noted that 1971 had a 21 percent larger Melt Index value than for 1985.

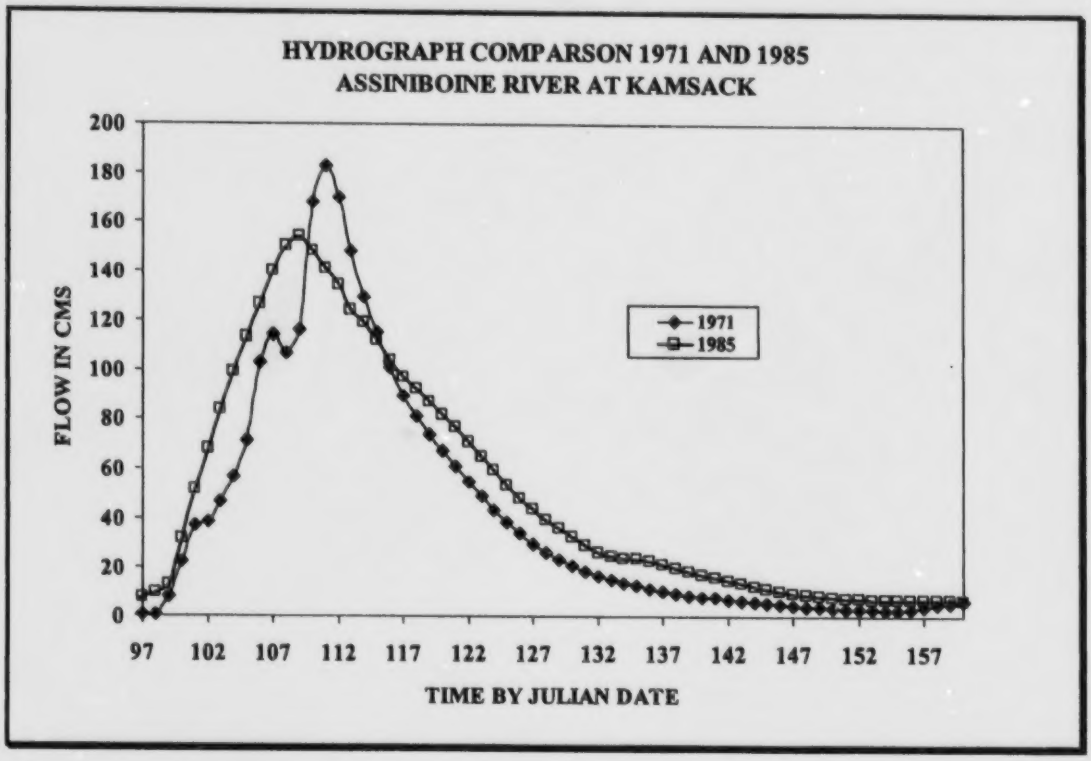
Figure 6.3
Hydrograph Comparison Assiniboine River at Kamsack for 1948 and 1997



As indicated on Figure 6.4, the rising limb of the runoff hydrograph in 1971 is steeper near the peak than in 1985. This is expected as 1971 had the higher Melt Index than 1985. Based on this information a higher yield for 1971 would be anticipated than for 1985. However, the opposite occurred, with 1985 actually having a 29 percent higher yield than 1971. In addition, the peak flow in 1985 occurred two days earlier and the recession limb of the hydrograph was much flatter, again consistent with expectations given the known landscape changes over this time period.

In this comparison of analogue years, both cases had higher yields in the more recent years. This suggests that for similar climatic conditions in the Basin, unit runoff volumes may be increasing with time, and that the timing of runoff may also have been affected.

Figure 6.4
Hydrograph Comparison Assiniboine River at Kamsack for 1971 and 1985



6.2.3 Mass Curve Analysis

A mass curve analysis was undertaken to determine if the impact of changing land management practices in the Basin could be detected on snowmelt runoff peaks and volumes. The analysis was restricted to the spring runoff period as the main runoff in the Basin normally occurs from snowmelt. Mass curves were derived based on recorded daily discharges for the period of record at the hydrometric gauging stations indicated in Table 6.3.

These stations are on tributaries to the Assiniboine River. The location of these streams is shown on Figure 6.5. It was felt the impacts would be most noticeable on the smaller streams as opposed to the main stem or large tributaries of the Assiniboine River. However, due to the short period of record on the smaller tributaries, the analysis was expanded to include the larger tributaries, Yorkton Creek and Whitesand River, and the Sturgis station on the upstream reach of the Assiniboine River. These stations have long-term records dating back to the early 1940s, which may predate the period of major drainage activity in the Basin.

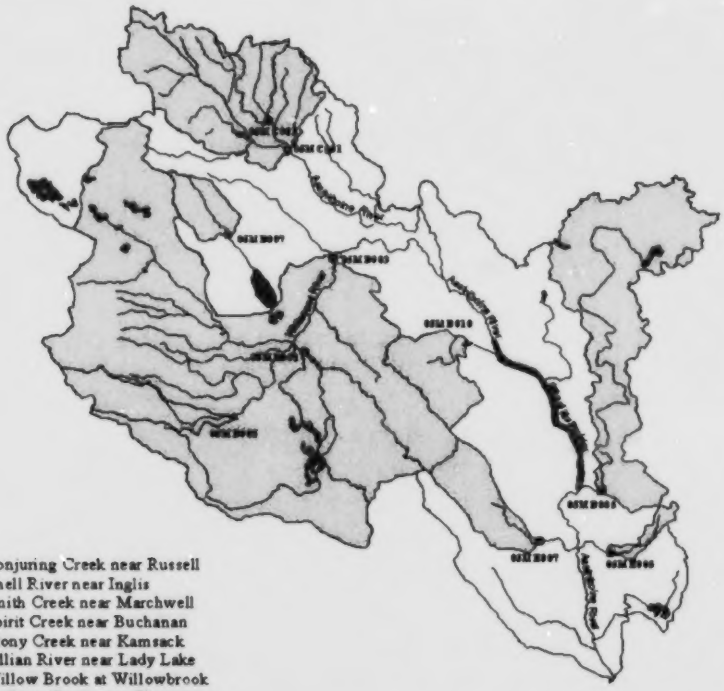
Table 6.3 - Hydrometric Gauging Station Information

NAME	PERIOD EXAMINED	GROSS DA (km^2)	EFFECTIVE DA (km^2)
Conjuring Creek near Russell	1959 to 1999	88.1	59.3
Shell River near Inglis	1948 to 1999	1999.0	1126.4
Smith Creek near Marchwell	1975 to 1999	436.2	57.8
Stony Creek near Kamsack	1971 to 1999	460.8	115.8
Spirit Creek near Buchanan	1957 to 1995	259.8	103.6
Lilian River near Lady Lake	1965 to 1999	229.0	152.6
Willow Brook at Willowbrook	1964 to 1998	402.0	95.3
Yorkton Creek near Ebenezer	1941 to 1999	2317.0	410.0
Whitesand River near Canora	1943 to 1999	8744.3	2002.3
Assiniboine River at Sturgis	1944 to 1999	1928.2	1143.0

Notes:

1. Effective drainage area is that area which contributes runoff to the main stream in a median (1:2) year from Martin, 1996.
2. Gross drainage area, defined by the topographical watershed divide.

Figure 6.5
Location Map of Hydrometric Stations


05ME005 - Conjuring Creek near Russell
05MD005 - Shell River near Inglis
05ME007 - Smith Creek near Marchwell
05MB007 - Spirit Creek near Buchanan
05MD010 - Stony Creek near Kamsack
05MC003 - Lillian River near Lady Lake
05MB005 - Willow Brook at Willowbrook
05MB001 - Yorkton Creek near Ebenezer
05MB003 - Whitesand River near Canora
05MC001 - Assiniboine River at Sturgis

As outlined in Table 6.4, the watersheds selected represent a range of different land covers in the Basin. Spirit Creek has 88 percent cropland. The Shell River watershed has only 17 percent cropland.

Table 6.4 - 1990s Land Covers[1]

WATERSHED	PERCENT LAND COVER					
	Cropland	Grass	Shrubs	Trees	Wetland	Water[2]
Conjuring Creek	47.3	19.8	0.0	26.9	6.0	0.0
Shell River	17.0	16.5	0.0	54.5	11.8	0.2
Smith Creek	79.1	6.0	4.3	4.3	6.3	0.0
Stony Creek	72.2	12.0	2.5	4.6	8.7	0.0
Spirit Creek	87.8	0.9	6.0	4.0	1.3	0.0
Lilian River	49.1	13.6	11.0	21.2	5.1	0.0
Willow Brook	40.0	26.0	16.0	12.0	6.0	0.0
Yorkton Creek	72.0	13.6	3.9	5.0	4.6	0.9
Whitesand River	63.9	18.6	6.9	5.5	4.4	0.7
Assiniboine River	41.0	11.0	9.0	31.0	7.0	1.0

Notes:
1. Source: WGTPP land cover database.
2. Greater than 100 hectares in size.

6.2.3.1 Derivation of Mass Curves

The peak flows and volumes for the entire period of record were used in producing the mass curves for each station to determine if long-term trends could be detected. The peak flows and volumes were normalized by dividing the spring peak flow or volume by their respective median value before accumulating the values for the period of record for each station. These mass curves of peak flow and volume are shown on Figures 6.6 and 6.7 respectively.

The mass curve for Willow Brook showed anomalously large runoff in both 1975 and 1976 which skewed its mass curves. Therefore, Willow Brook was excluded from further analyses.

From the mass curves it is interesting to note that only the mass curve of Spirit Creek volumes indicates an increasing trend relative to the other curves. The mass curve of volumes for Spirit Creek parallels the curve for Conjuring Creek until about 1972, after which it shows a diverging trend

Figure 6.6
Mass Curve of Spring Peak Flows

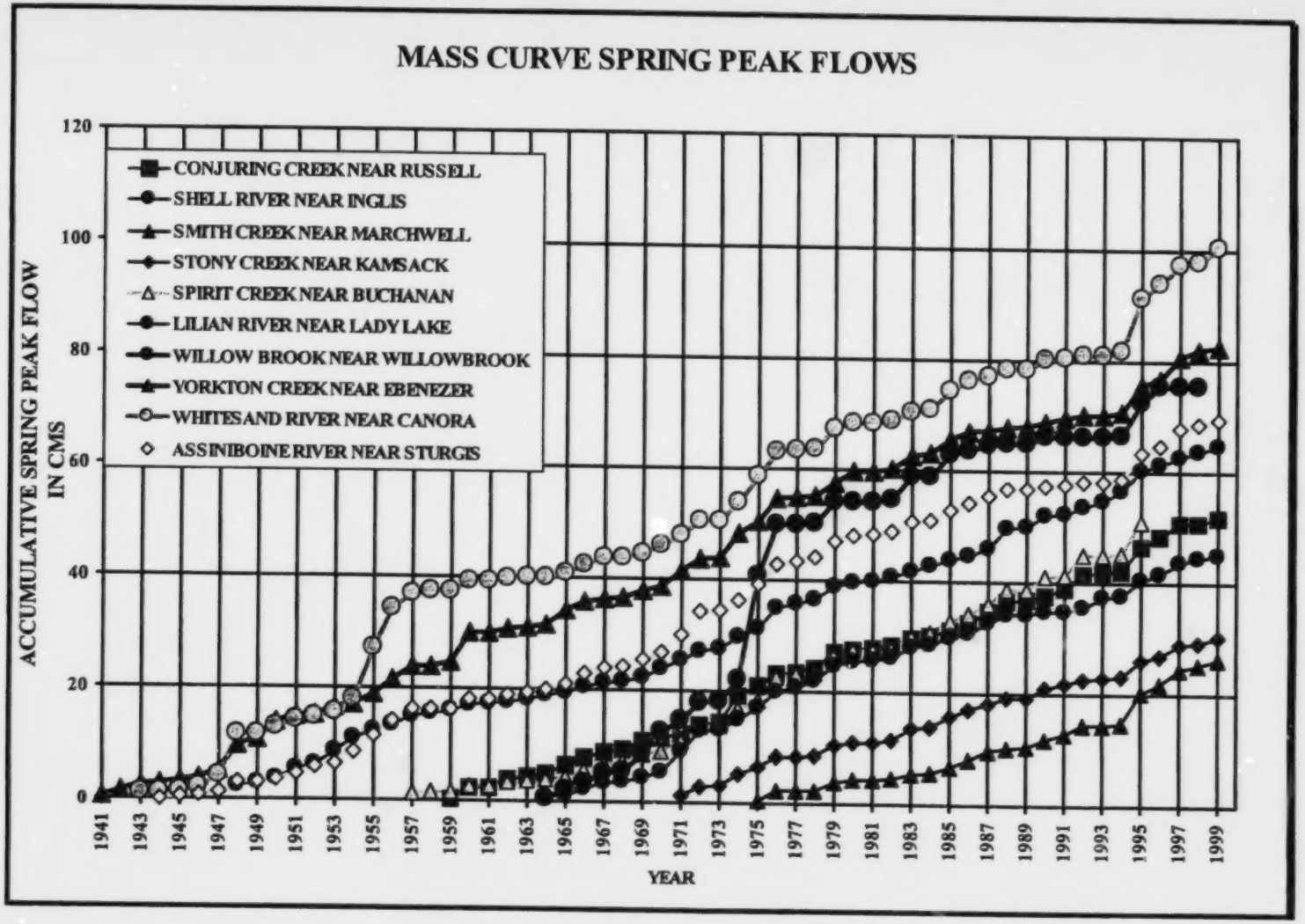
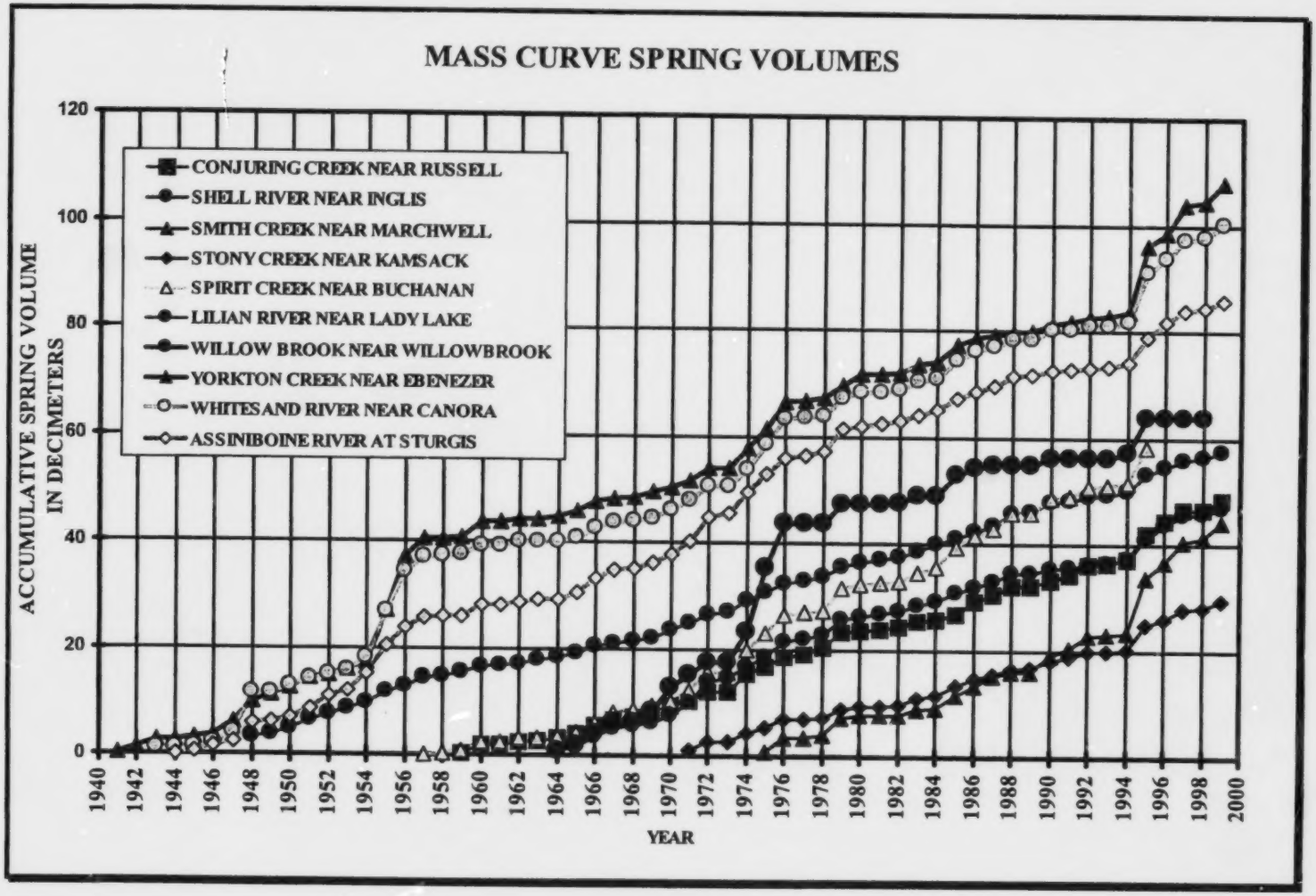


Figure 6.7
Mass Curve of Spring Volumes



6.2.3.2 Analysis of Stationarity

A time series of hydrologic data is said to be stationary if the frequency distribution of the data remains constant over time. The most common type of non-stationarity is the presence of a trend in the hydrologic data set. A very simple test for presence of trend and its significance can be made on the Spearman rank order correlation coefficient. The coefficient is computed from the pairs consisting of a flow and its associated rank. An attempt was made to use the Spearman rank test in Environment Canada's Consolidated Frequency Analysis package (Pilon *et al.*, 1985). However, the Spearman rank test was not sensitive enough to detect any changing trend.

Therefore, to test for the degree of stationarity in the peak flow and volume data a linear trend analysis was applied to the mass curves for each station. This was based on the hypothesis that the degree of linearity indicates the stationarity of the data, which in turns reflects the net impact of changing agricultural practices. From the Handbook of Applied Hydrology, "If there is no linear relationship, the r (correlation coefficient) = 0. If there is a functional linear relationship, $r = \pm 1$. All values of r between these limits describe the various degrees of correlative association. The greater the absolute value of r, the greater the linear correlation" (Chow, 1964 pg 8-54). Therefore, the correlation coefficient was used to provide an indication of stationarity of the peak flows and volumes. The greater the correlation coefficient the greater the stationarity of the data. The results are shown in Table 6.5.

Table 6.5 - Mass Curve Correlation Coefficient for Entire Period of Record

WATERSHED	CORRELATION COEFFICIENT	
	Peak Flows	Volumes
Conjuring Creek near Russell	0.9961	0.9940
Shell River near Inglis	0.9949	0.9949
Smith Creek near Marchwell	0.9637	0.9550
Stony Creek near Kamsack	0.9962	0.9890
Spirit Creek near Buchanan	0.9892	0.9907
Lilian River near Lady Lake	0.9835	0.9874
Yorkton Creek near Ebenezer	0.9967	0.9867
Whitesand River near Canora	0.9901	0.9901
Assiniboine River at Sturgis	0.9945	0.9944

The peak flow and volume data from the mass curve analysis indicate all the stations have a high degree of stationarity with time. The Shell River, Conjuring Creek and Assiniboine River at Sturgis showed the greatest stationarity in the data. However, both Spirit Creek and Stony Creek also showed relatively high degrees of stationarity. For Stony and Spirit Creeks, it is possible that much of the known existing drainage occurred prior to the start of the recorded data. If this is the case, the impacts of agricultural practices are already incorporated in the data and can not be detected by the mass curve analysis.

An aerial photo interpretation of drainage by Ducks Unlimited in Township 26, Range 32 W1, in the headwaters of Stony Creek, indicated that 52 percent of the wetlands had been impacted by drainage by 1980 with this increasing to 60 percent by 1998. Similarly, in the headwaters of Spirit Creek, Township 33, Range 7 W2, 73 percent of the wetlands had been impacted by drainage by 1980, with this increasing to 85 percent by 1998. Statistics Canada census data were used to check these findings. The rural municipality data in Table 6.6 was used as an indication of the changes occurring in the various watersheds.

Table 6.6 - Watershed Representative Rural Municipality Data

WATERSHED	RURAL MUNICIPALITY
Conjuring Creek	Russell
Shell River	Shell River
Smith Creek	Churchbridge
Stony Creek	Calder
Spirit Creek	Buchanan
Lilian River	Preeceville
Yorkton Creek	Orkney
Whitesand River	Insinger
Assiniboine River	Preeceville

As can be seen from the plot of Statistics Canada data on Figure 6.8, the Spirit Creek watershed had the highest percentage of improved land in 1956. From 1966 to 1996 there has been very little change in the percentage of improved land in the Spirit Creek watershed. In the Stony Creek watershed from 1971 to 1996 the percentage of improved land increased by only three percent. Therefore, the major impacts of agricultural practices are already incorporated within the data of Spirit and Stony Creeks and any such impacts are not evident in the mass curve analyses for these stations. The mass curve for Smith Creek near Marchwell indicated the least stationarity in peak discharges and volumes.

The magnitude of the peak flow or volume in a given year is largely determined by the snowmelt conditions and these may not be the same at all stations but such differences should even out over the longer term. In order to compare statistical measures of linearity between stations in a meaningful way, a common period of record, which unfortunately is only 1975-95, should be used. Therefore, the test of linearity was applied to only this period. The results are provided in Table 6.7.

Figure 6.8
Improved Area as Percent of Total Rural Municipality

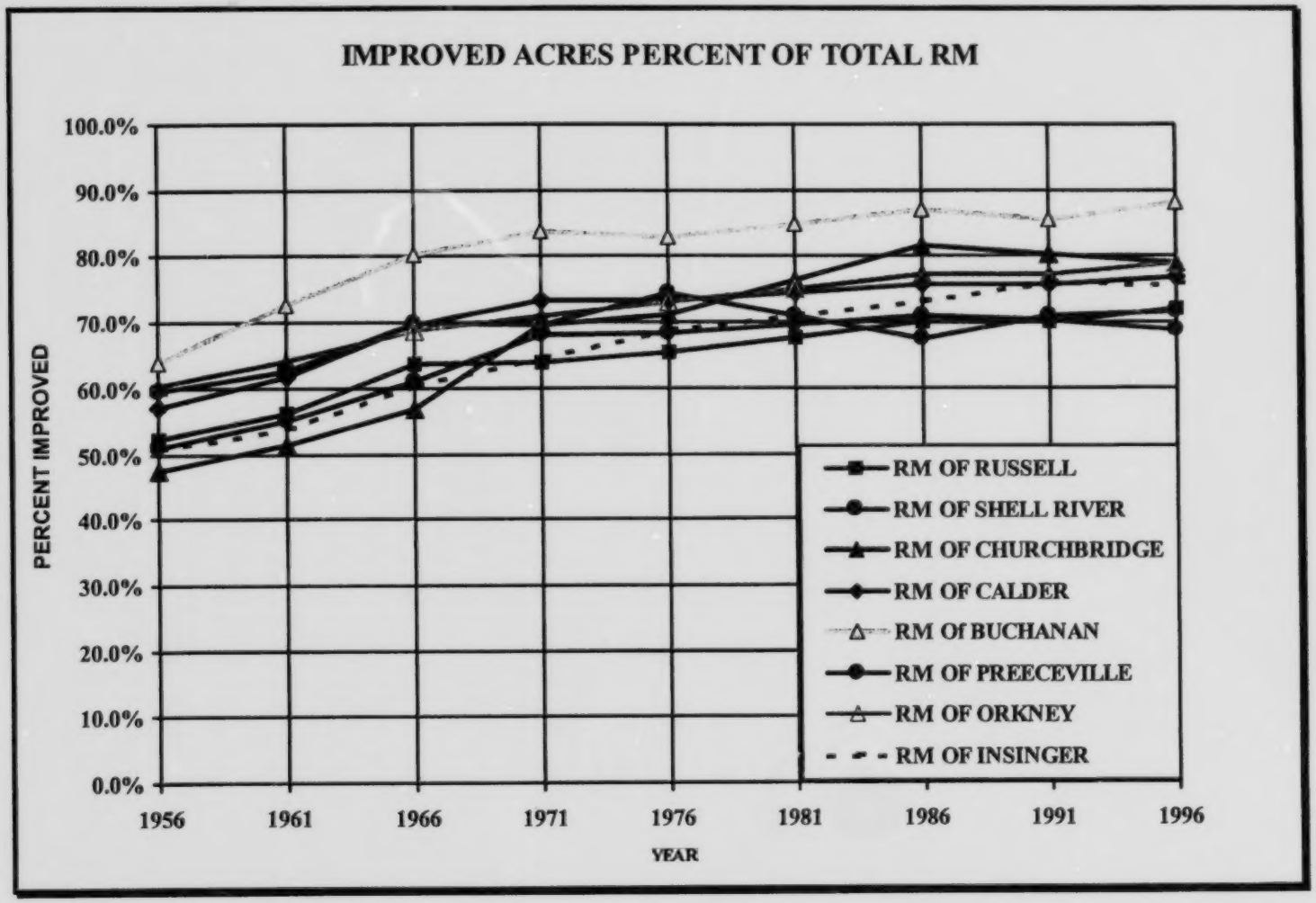


Table 6.7 - Mass Curve Correlation Coefficients for Period 1975 to 1995

WATERSHED	CORRELATION COEFFICIENT	
	Peak Flows	Volumes
Conjuring Creek near Russell	0.9915	0.9907
Smith Creek near Marchwell	0.9733	0.9650
Shell River near Inglis	0.9925	0.9958
Stony Creek near Kamsack	0.9944	0.9870
Spirit Creek near Buchanan	0.9907	0.9913
Lilian River near Lady Lake	0.9829	0.9874
Yorkton Creek near Ebenezer	0.9813	0.9428
Whitesand River near Canora	0.9700	0.9700
Assiniboine River at Sturgis	0.9845	0.9861

These results are similar to that obtained using the entire period of record.

6.2.3.3 Analysis of Trend

To check the trend in the peak flow and volume data a polynomial fit was applied to each station's mass curve. Therefore, the smaller the value of the chi-squared component in the polynomial equation, the less the impact of agricultural land use changes over time.

Table 6.8 - Mass Curve Polynomial Chi-squared Parameter

WATERSHED	CHI-SQUARED COMPONENT	
	Peak Flows	Volumes
Conjuring Creek near Russell	0.0037	0.0075
Smith Creek near Marchwell	0.0387	0.0696
Shell River near Inglis	0.0073	0.0035
Stony Creek near Kamsack	0.0020	0.0136
Spirit Creek near Buchanan	0.0145	0.0119
Lilian River near Lady Lake	-0.2150	-0.0150
Yorkton Creek near Ebenezer	-0.0025	-0.0062
Whitesand River near Canora	-0.0054	-0.0054
Assiniboine River at Sturgis	0.0090	-0.0042

All the smaller tributary stations' peak flow and volume data except for Lilian River show an increasing trend over time. These trends are much greater for runoff volumes than for peak flows, suggesting that peak flow may be less impacted by changes in land cover than are volumes. The peak flows and volumes for Lilian River as well as Yorkton Creek, Whitesand River, and Assiniboine River at Sturgis (volumes) appear to be decreasing. The Shell River, Stony and Conjuring Creeks showed the least increase in peak flows and volumes with time followed by Spirit Creek. As previously discussed, the major impacts of agricultural practices

are already incorporated in the data for Spirit and Stony Creeks. Smith Creek has the greatest trend of increasing peak flows and volumes with time.

6.2.3.4 Summary

The peak flow and volume data for tributary streams in the Basin display a high degree of stationarity with time. The impact of changing agricultural practices such as drainage of wetlands, clearing of trees and bush, and breaking of native grasslands are difficult to detect because Statistics Canada data indicate such practices largely occurred prior to the availability of streamflow data. However, all the smaller tributary stations examined, except Lilian River, generally have increasing peak flows and volumes with time. Lilian River exhibits a decrease in peak flows and volumes with time.

The chi-squared coefficient values for the mass curves indicate that both peak flows and runoff volumes are increasing with time at most of the smaller tributary streams, and that this trend is much greater for volumes than for peak flows. From a visual examination of the mass curves, Spirit Creek spring volumes are increasing relative to the other watersheds. The increase starts about 1972. Spirit Creek has the highest percentage of cropland of the watersheds examined. It would appear that agricultural practices in the Spirit Creek watershed are impacting runoff volumes in this intensively cropped watershed. The Spirit Creek watershed has 87.8 percent cropland, and 85 percent of the wetlands evident in 1949 have since been impacted by drainage.

6.2.4 Sub-Watershed Travel Times

There are several streamflow gauging stations located throughout the Basin. An attempt was made to determine if there has been any relative change to hydrograph peak travel times occurring within the period of record. Records at a number of stations were examined to observe if consistent patterns were apparent. This could indicate that changes within individual sub-watersheds such as land use alterations and/or drainage are affecting hydrograph travel times within the various tributaries. Table 6.9 lists the gauging stations that were examined.

The records for the above stations were reviewed to determine the maximum daily flow for the spring period (March, April, May) for each year of record. It was decided to only utilize larger than average flows, since this would avoid very low flow situations which are of little consequence because they generally occur as a result of very little snow accumulation. The estimated peak discharges for a 1 in 2-year flood event (1:2) at each station were obtained from the Sask Water Publication, 'Magnitude and Frequency of Peak Flows and Flow Volumes in Saskatchewan' (Taylor *et. al.*, 1993). Thus, only the years in which the respective station's 1:2 peak flow was exceeded were selected for further analysis.

The calendar dates for the annual peak flows were converted to Julian dates. This facilitated the graphical comparison of peak flow dates by year for various combinations of the stations. To compare the Julian dates, the peak flow date for one station was subtracted from the other for the overlapping years of record. These results were plotted linearly versus time in years to determine

Table 6.9 - List of Hydrometric Gauging Stations Examined for Changing Travel Times

Station Name	Station Number	Effective Drainage Area (km^2)	Gross Drainage Area (km^2)	Years Examined	Watershed Development Classification
Crooked Hill Creek near Canora	05MB006	104.4	582.0	1956 - 1992	Developed
Spirit Creek near Buchanan	05MB007	103.6	259.8	1957 - 1995	Developed
Assiniboine River at Sturgis	05MC001	1143.0	1928.2	1957 -1997	Natural
Lilian River near Lady Lake	05MC003	152.6	229.0	1966 - 1997	Natural
Conjuring Creek near Preeceville	05MC004	143.5	255.6	1966 - 1992	Recently Developed
Smith Creek near Marchwell	05ME007	57.8	436.2	1975 - 1997	Recently Developed

visually if there were any apparent trends or consistencies. It was hoped that by comparing sub-watersheds it would be possible to determine if the 'travel times' characteristics had been altered by development.

The data of individual stations was also plotted to determine if there were any apparent trends for the individual stations over time. Stations were loosely categorized into developed or developing and natural or stable as indicated in Table 6.9.

The results indicated that for both scenarios, individual and compared stations, no trends could be observed. The common period of record is quite short, particularly since only the larger half of the runoff years were included in the analysis. In addition, and discussed in Section 6.2.3, most of the existing agricultural development occurred prior to the period of record so that any impacts of such developments are inherent in the recorded data. Finally, the relative timing of peak flow is substantially influenced by climatic conditions during the melt period, which may vary considerably across the Basin in any given year.

6.2.5 Regression Analysis

The Manitoba Flood Forecast Center has developed regression equations to forecast the spring runoff potential into Lake of the Prairies. One of the locations at which forecasts are made is the Assiniboine River at Kamsack. The parameters used in the derivation of the forecast equations were previously discussed in Section 6.2.2.

6.2.5.1 Split Sample Analysis

For the Assiniboine River at Kamsack, the forecasting equation is based on the historic streamflow records for the period 1948 to 1999. To determine if changing agricultural land use

practices in the Basin above Kamsack have had an impact on the spring runoff volume, the period of record was subdivided into two equal 26-year periods. The two equal periods were from 1943 to 1973 and from 1974 to 1999.

A multi-regression analysis was conducted on the two periods. The dependant variable was RO, with the independent variables P, MI, and API. The equations of the spring runoff potential derived for two period are as follows:

(1948 to 1973): $RO = 1.530 \times 10^{-8} (P)^{2.658} (MI)^{0.100} (API)^{1.488}$ $(r^2 = 0.962)$
(1974 to 1999): $RO = 0.128 \times 10^{-8} (P)^{2.665} (MI)^{0.527} (API)^{1.856}$ $(r^2 = 0.927)$

The two multi-variable regression equations were then applied to the data for the entire period 1948 to 1999. The comparison of the annual spring runoff volumes forecast by the two equations indicates that on average the spring runoff volume estimated by the equation for the period 1974 to 1999 was 12 percent higher than the equation for the period 1948 to 1973. The annual spring runoff volumes and the variance resulting from the two equations are shown on Figure 6.9.

This analysis would appear to suggest that agricultural land practices in the Basin above Kamsack are resulting in increased spring runoff volumes. The analysis is limited by the short period of record and by the fact that agricultural land use practices have been continuously changing through the period analyzed.

6.2.5.2 Inclusion of Land Cover Index

The forecast equations for the two periods have vastly different coefficients for the same independent variable, so that each variable (P, MI and API) may have a different relative impact on RO depending on the climate for its period. To remove the impact of climate the regression analysis was applied to the entire period with an additional variable representing improved area in the Basin. The percentage of improved area in the Basin was estimated from the Statistics Canada data which indicate that 56 percent of the Basin was improved in 1956, with this percentage increasing to 76.5 percent by 1996. The graph of improved area is shown on Figure 6.10. The regression analysis was conducted for the full 52-year period with two additional variables:

- LUI = Percentage improved area in the Basin.
- PSR = Previous spring runoff in mm.

For the years 1948 to 1956, the percentage of improved area (LUI) was set equal to 56.0 percent. For each year between 1956 and 1996 the LUI parameter was interpolated from the Statistics Canada data in Figure 6.10. For the years 1997, 1998 and 1999 the LUI for 1996 from the Statistics Canada data was increased by 0.1 per year, based on the previous ten years' trend. The derived regression equation was:

$$RO = 4.501 \times 10^{-10} (P)^{2.784} (MI)^{0.328} (API)^{1.194} (LUI)^{0.893} (PSR)^{0.098} \quad (r^2 = 0.938)$$

Figure 6.9
Assiniboine River at Kamsack Spring Runoff Volumes
Estimated by Split Sampling Techniques

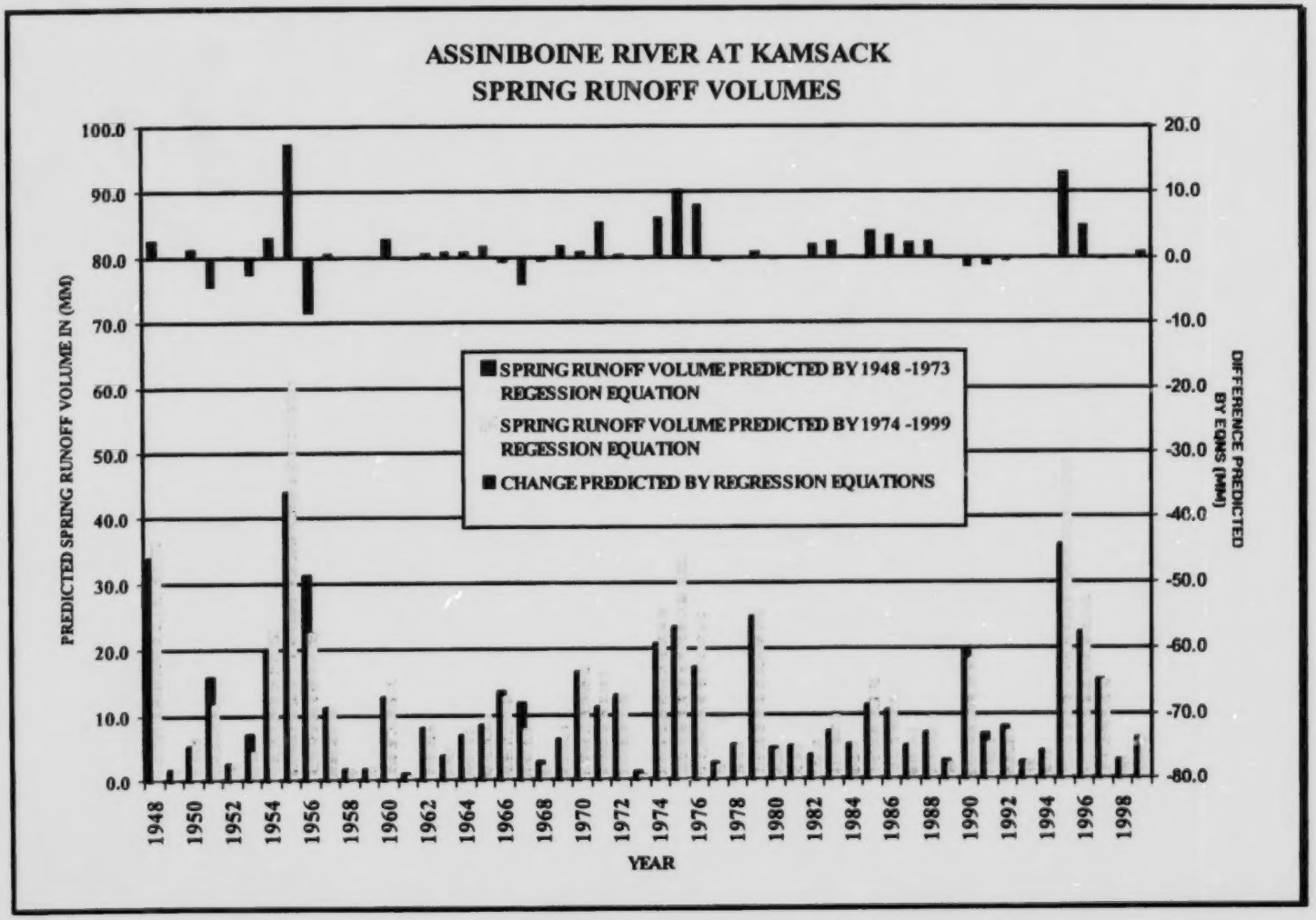
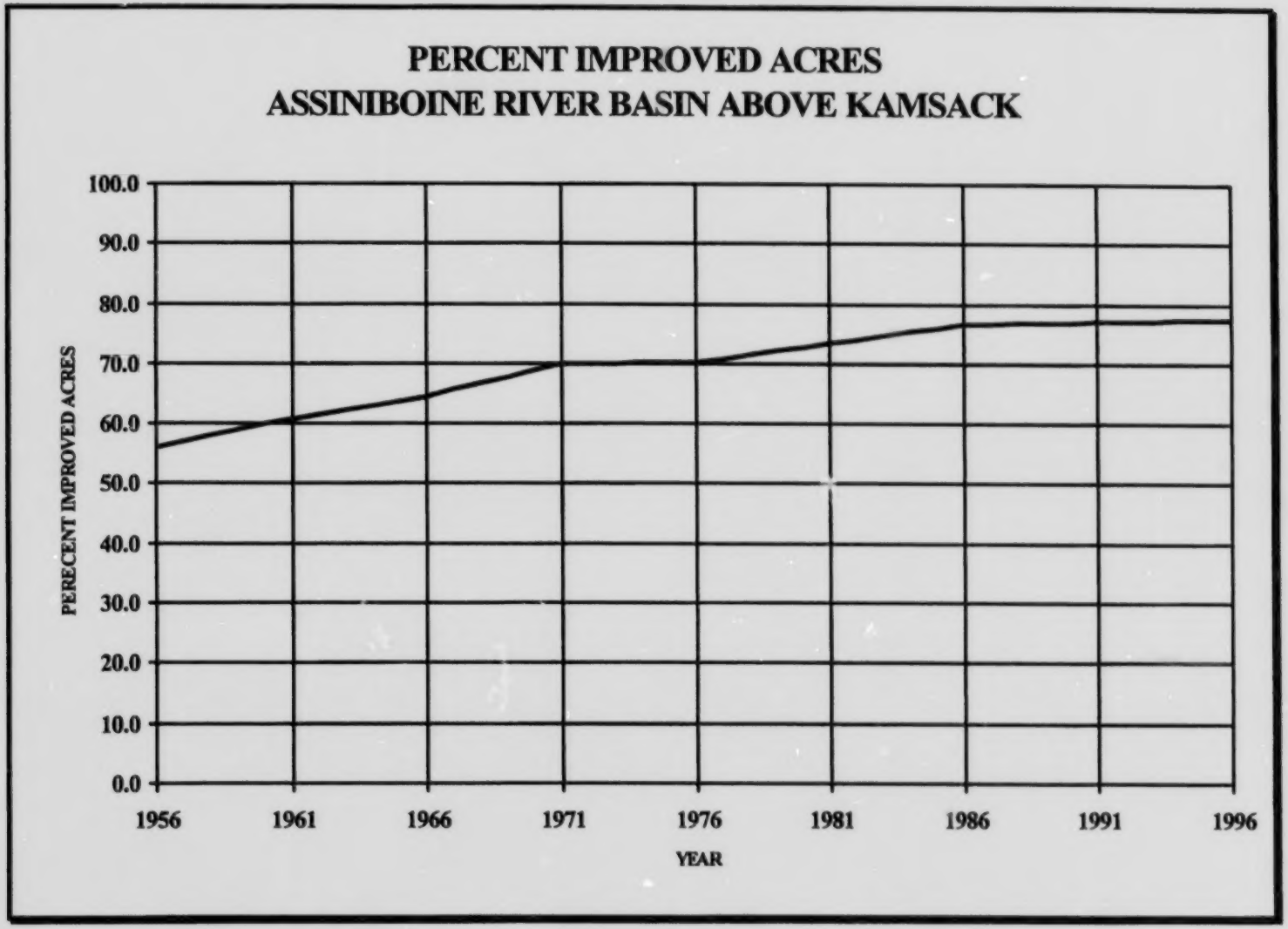


Figure 6.10
Percent Improved Area Upper Assiniboine River Basin above Kamsack



To determine the significance of the land cover changes in the Basin, the regression equation was applied to the 52 year period for two scenarios. Scenario 1 assumed that the 1956 percentage of improved area (56 percent) was constant for the entire period. The second scenario assumed the 1996 percentage of improved land (76.5 percent) was constant for the entire period. The estimated spring runoff volumes for the two scenarios are shown on Figure 6.11.

The analysis indicates that the change in the historic improved area in the Basin above Kamsack has resulted in the accumulated spring runoff volume over the 52 year period at Kamsack increasing in the order of 33 percent. As indicated previously, the year 1995 was an extreme runoff event in the Basin.

To determine how strong the relationship was between the magnitude of the runoff (RO) and the predicted change in runoff, a correlation was undertaken between the two. The resulting correlation coefficient of 0.862 indicates a strong relationship between the magnitude of the runoff and increased runoff volumes from land use changes. In other words, the greater the spring runoff volume the greater the impact of land use changes on the volume.

The preceding analysis removes the impacts of climate by applying the analysis to the entire period of record. There are still uncertainties in the analysis, however, it does indicate a trend of increasing spring runoff volumes on the Assiniboine River at Kamsack with increasing cropped area.

6.2.5.3 Mass Curve Analysis

To determine if a noticeable change could be detected in the spring runoff volumes for the Assiniboine River at Kamsack, a mass curve was constructed for the period 1948 to 1999. The mass curve of recorded spring runoff volumes is shown on Figure 6.12. A linear regression analysis of the mass curve indicates a high degree of stationarity in the data with a correlation coefficient of 0.9864. Also, there is no statistical evidence of an increasing trend in the recorded data as the chi-squared component of the polynomial fit to the data is only 0.0002, which is almost a straight line.

Five and ten year running average slopes were then computed for the mass curve. It was found that the minimum slope for the 1990s was steeper than for the 1950s. Although this could be due to the different climatic periods it does seem to indicate that the spring runoff volume on the Assiniboine River at Kamsack has increased over time. For comparison purposes the corresponding mass curves of the estimated runoff for the two scenarios of the 1956 and 1996 LUI are shown on Figure 6.12. These two curves envelop the recorded data and exhibit the same trend. The change in runoff with constant land use is very subtle and hard to detect from the mass curve analysis.

Figure 6.11
Assiniboine River at Kamsack Spring Runoff Volumes
Predicted by use of Land Cover Index

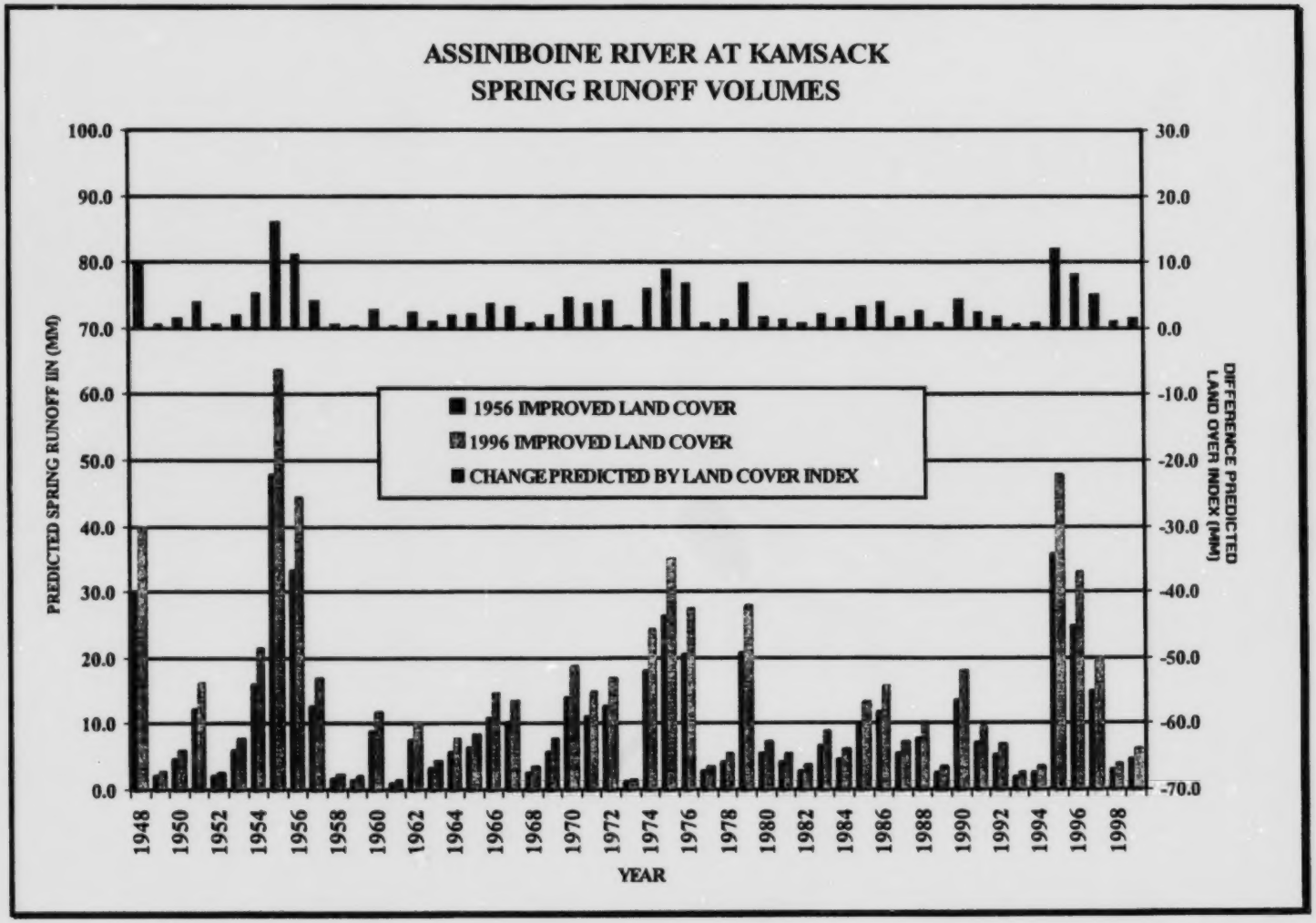
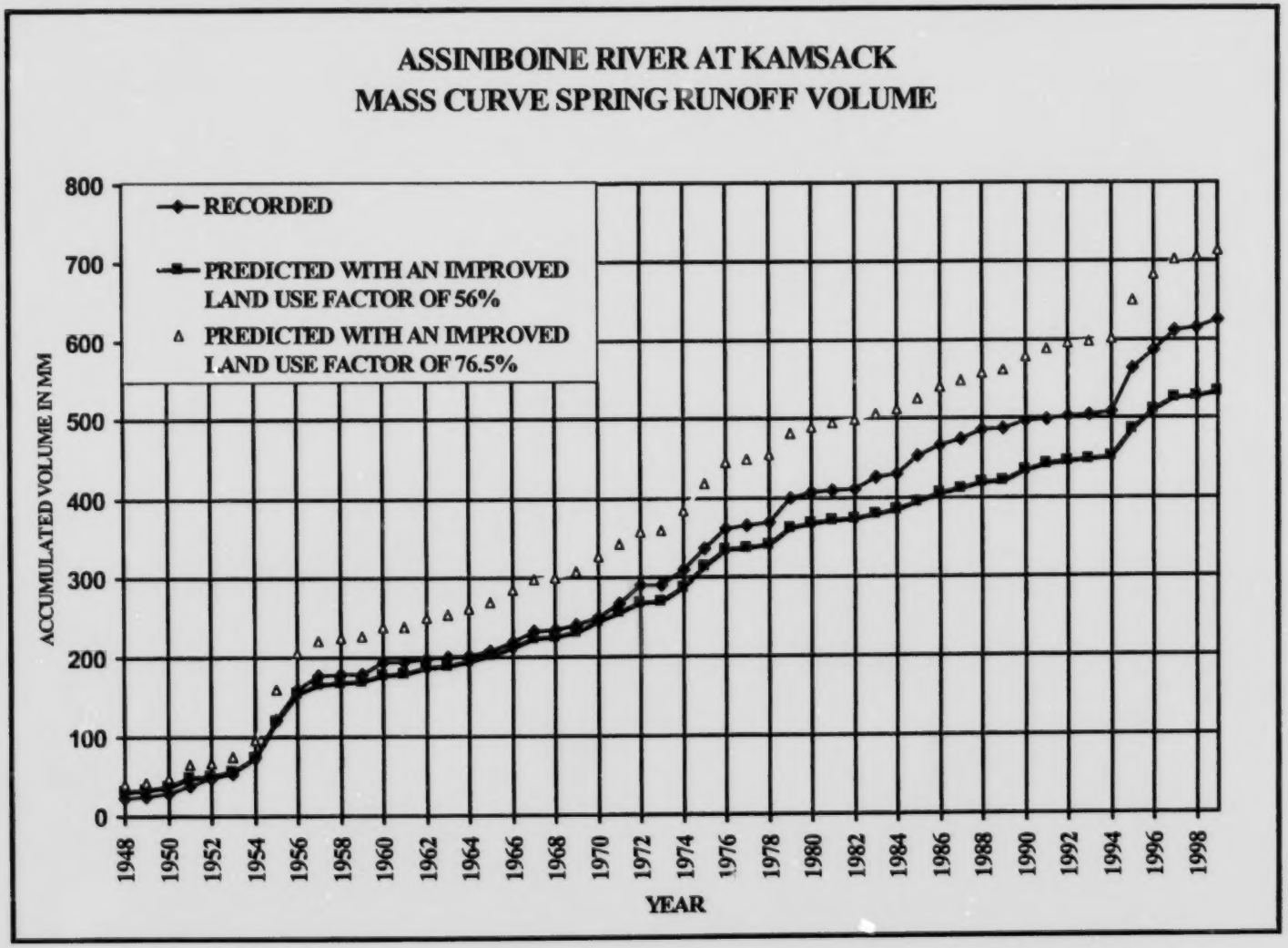


Figure 6.12
Assiniboine River at Kamsack Mass Curve Spring Runoff Volume



6.2.5.4 Conclusions of Regression Analysis

The analysis of spring runoff volumes of the Assiniboine River undertaken using regression techniques incorporating winter and effective spring precipitation, melt index, antecedent moisture conditions, improved area in the Basin and the previous spring runoff indicates increasing runoff over time. This technique attempts to filter out climatic factors. The change is very gradual and can not be detected in the mass curve analysis. The independent variable representing the improved area in the Basin indicates that the 1996 level of improved lands could have increased runoff by 33 percent compared to the 1956 level of improved lands. However, the analysis can not distinguish between the incremental effects of such activities as clearing of bush, drainage of sloughs and wetlands, breaking of native grasslands, road development, and agricultural cultivation practices.

6.2.6 Summary of Streamflow Analysis

From the comparison of analogue years for the Assiniboine River at Kamsack, it appears that unit runoff volumes within the Basin are increasing over the time period examined. A mass curve analysis of peak flow and volume data for tributary streams in the Basin could not detect the time period when this change may have occurred. The mass curves exhibit a high degree of stationarity with time. This is because, as indicated by Statistics Canada data, agricultural practices such as drainage of wetlands, clearing of trees and bush, and breaking of native grassland, largely occurred prior to the availability of streamflow data. A regression analysis of spring runoff volumes of the Assiniboine River at Kamsack incorporating winter and effective spring precipitation, melt index, antecedent soil moisture conditions, improved area in the Basin and the previous spring runoff confirms the hypothesis that runoff volumes increase with increases in improved area. This technique attempts to filter out climatic factors. The regression analysis indicates that the 1996 level of improved lands could have increased the accumulated runoff over the 52-year period 1948 to 1999 by 33 percent compared to the 1956 level of improved lands. However, this analysis can not distinguish between the effects of individual land cover changes or agricultural practices.

Based on the short period of concurrent streamflow and meteorologic data available, the conclusion from the several methods of streamflow analysis is that it appears, mathematically, that runoff volumes have increased over time. From a water management perspective, this change has implications on management of lakes and reservoirs. Given that the changes are occurring, the Committee recommends that water management plans for lakes and reservoirs be reviewed to determine their ability to handle increasing runoff volumes, and that agricultural and wildlife habitat management programs consider the effects that land use may have on runoff.

6.3 Drainage Area Analysis Techniques

One of the approaches which can be taken to assess the impact of drainage on the hydrology of an ungauged watershed involves using the increase in contributing drainage area resulting from drainage projects and recorded streamflows on a similar watershed. This section reviews one

document which outlines this technique and two reports in which this technique was applied in the Basin.

6.3.1 Methodology

The first document reviewed in this section was written by R. S. Pentland (1980). The author documents a technique which is used by hydrologists as a statistical approach to determine the effect of agricultural drainage projects on contributing drainage areas. The technique described is a generalized approach based on a contributing drainage area concept. This technique implies that drainage projects increase the drainage area directly contributing to flow.

The technique takes into account the fact that the poorly defined drainage channels, hummocky terrain, and flatter stream gradients, characteristic of prairie watersheds, are manifested in large areas which do not contribute to runoff during low to median runoff events (a median event has a 50 percent probability of being equaled or exceeded in any given year, which is also referred to as an annual recurrence interval or annual return period of 1:2). In hydrologic terms, the effective drainage area is defined as that proportion of the watershed that contributes to runoff during a median runoff event, as compared to the gross drainage area which defines the area enclosed by the watershed topographic divide. Delineation of the effective drainage area is a subjective exercise depending to a large degree on professional judgment. In general, the effective drainage area excludes areas containing a lot of wetlands which do not show any clearly defined outlet channels.

As meteorologic inputs and other watershed conditions contribute to a runoff event that exceeds the magnitude of the median event, a progressively greater proportion of the watershed is assumed to contribute to the flow, due to the filling and spilling of water otherwise detained in the sloughs and potholes. It is hypothesized that, ultimately, at some extremely rare, high flow event, the contributing area becomes coincident with the gross drainage area. A runoff event with a recurrence interval of between 1:500 or 1:1000 is usually assumed to describe the event at which an entire prairie watershed might contribute to the runoff. However, the distinction between which of the two might be more applicable is a matter of judgment, based on watershed characteristics.

Application of the technique is initiated by deriving a frequency distribution of pre- and post-drainage contributing areas on probability paper. First the pre-drainage effective drainage area is plotted at the median probability and is joined, by a straight line, to the gross drainage area which is plotted at an appropriate extreme probability position (commonly the 1:500 or the 1:1000 frequency is deemed appropriate based on the watershed characteristics). Next the post-drainage effective drainage area is plotted, also at the median point on the frequency curve and also joined to the gross drainage area by a straight line. There are now two frequency lines representing pre- and post- drainage conditions starting at the median frequency and converging at the gross drainage area plotted at the extreme frequency side of the frequency distribution. Thus, for any required frequency the corresponding pre-drainage and post-drainage contributing drainage areas can be extracted.

Given a frequency curve of the pre-drainage flood volumes, a frequency curve of post-drainage runoff volumes can be developed. The post-drainage runoff volume for any selected frequency is derived as the product of the pre-drainage volume, for that frequency, times the ratio of the post- to pre-drainage contributing drainage areas, for the corresponding frequency. It is evident that by using this technique, the effect of wetland drainage decreases as the event frequency decreases (i.e., a higher flood event) and the ratio of the post- to pre-drainage ratio approaches unity.

There are several limitations to this technique, not the least of which is the subjective nature of the effective drainage area delineation. Furthermore, while the method is suitable for small watersheds its application to large, complex basins is precluded by the variation and complexity of the drainage patterns found in large basins. The main difficulty in large basins lies in the fact that within the effective drainage areas are many unaccounted for pockets of dead drainage. The technique neglects the fact that in large drainage basins much of the agricultural drainage which occurs is within the area defined as the effective drainage area and thus does not add to the pre-drainage effective drainage area.

Probably the greatest shortcoming is the simplistic assumption that drainage increases flow volumes. While drainage will not decrease runoff volumes, the magnitude of any increase depends on a number of factors in addition to drainage area.

Another limitation of this technique is the fact that it does not and can not account for changes in the hydraulic performance of the stream network that usually accompanies drainage projects. That is, not only is the effective drainage area increased, but the channel networks are "improved" in order to convey greater flows in a reduced time period without exceeding the bankfull capacity of the channel and causing flooding of adjacent agricultural land. Also not accounted for in this approach are any temporary storage ponds, control works, etc., which may be designed into a drainage project to mitigate any effects of increased flow rates.

Finally, an inherent assumption in this technique is that the watershed at which streamflows have been recorded is hydrologically similar to the watershed of the drainage project. While hydrologists attempt to select the most appropriate streamflow station, there is often only a limited selection from which to choose. Field observation of the watershed of the streamflow station and/or the drainage project may not be possible, and there is rarely an opportunity to confirm the findings of this approach by field measurement or observation of flows in the drained watershed.

Notwithstanding the limitations of the drainage area technique, for many applications involving smaller prairie watersheds, it is the only practical method available. The PPWB agreed to use this approach as an interim working procedure to assess the post-drainage runoff problems until research studies determined the effects of artificial drainage on downstream flow in prairie streams.

6.3.2 Application to the Basin

6.3.2.1 1983 Saskatchewan Environment Study

The first major report which describes the application of the above methodology was issued in 1983 (Gobert, 1983). This Sask Environment report evaluated the impacts of existing and proposed drainage projects on flows in the Assiniboine and Whitesand rivers in Saskatchewan. The report was done at the request of the Saskatchewan Agriculture and Food with three objectives:

1) To determine the effect of existing organized drainage works constructed prior to 1952;
2) To determine the effect of existing organized drainage works constructed under Saskatchewan Agriculture and Food's flood control and drainage policy; and
3) To determine the effect of proposed organized drainage works which may be built.

The study considered the changes in peak flows and in duration of flooding at seven locations in the Saskatchewan portion of the Basin. On the Whitesand River, these locations were: below the confluence with Yorkton Creek, at Highway 9, near Canora, and at Kamsack above the confluence with the Assiniboine River. On the Assiniboine River, these locations were: at Highway 9, at Kamsack above the confluence with the Whitesand River, and at Kamsack below the confluence with the Whitesand River.

The study examined a total of 20 existing and proposed drainage projects. Four existing projects were considered to date back prior to 1952: Canora, Invermay, Mikado, and Rama. These four projects had a combined post-drainage effective area of 54.5 km^2 and a combined gross drainage area of 188 km^2. An additional eleven projects existed upstream of Kamsack by 1981: Buchanan East and North, Burgis, Canora South, Christiana, Crooked Hill Creek, Donwell North, Strathcona, Tiny East, and Yorkton North and South. Together with the pre-1952 projects, the 15 existing projects had a combined post-drainage effective area of 339 km^2 and a combined gross drainage area of 991 km^2. The five proposed projects were Amsterdam, Ebenezer, and Hyas South drainage projects as well as the Good Spirit Lake and Horseshoe Lake control structures, with their associated outlet channel improvements. The three proposed drainage projects had a combined post-drainage effective area of 43.2 km^2 and a combined gross drainage area of 111 km^2.

Existing or proposed drainage projects which had no increase in effective drainage area were not included in the study as it was recognized that the drainage area approach would show that they would have no effect on downstream flows. These included projects whose only works involved channel improvements and others which were located entirely within the pre-drainage effective area.

The drainage area ratio technique was used to determine the pre-drainage and post-drainage flows at the outlet end of the 20 projects listed above. Peak flows and March-through-June flow volumes were transferred from the most appropriate of five stations in the Basin considered to be

largely unaffected by drainage: Stony Creek near Stenen, Assiniboine River at Sturgis, Whitesand River near Springside, Willow Brook near Willowbrook, and Lawrie Creek near Insinger. Peaks and volumes for return periods of 2, 10, 25, 50, 100, and 500 years were transferred.

A routing model, SIMPAK, was then used to route the flows from the drainage projects plus flows from the five upstream gauges largely unaffected by drainage and local inflows to the seven key locations along the Whitesand and Assiniboine rivers.

The study found that then existing drainage works did have a significant effect on flows in the watershed. Future projects then being considered were found to have considerably less incremental impact than the projects already existing.

In general, the largest percentage increase in peak flow due to drainage was felt for the 1:2 event with declining impact for the higher return periods. This is expected as a direct consequence of the methodology used. Another finding was that the least impacted locations were those having the least amount of drainage upstream such as the two locations on the Assiniboine River above the Whitesand River and at the Whitesand River below Yorkton Creek. Conversely, the most heavily impacted locations were on the Whitesand River at Highway 9, near Canora, and at Kamsack and on the Assiniboine River at Kamsack below the confluence with the Whitesand River.

One finding of the study was that the construction of a control structure at the outlet of Good Spirit Lake would have the potential to offset increased peak flows from existing drainage projects to the extent that peak flows in high runoff years at the four locations below the Good Spirit Lake outlet would be reduced from peaks experienced with the existing drainage projects alone. The study did not examine the effect the control structure might have on flow volumes.

Similar trends were found for duration of flood flows. The greatest impact was simulated for the 1:2 event, with declining impact at the higher return periods. Again, the impact of controlled storage and outflow rates at Good Spirit Lake were found to offset the impact of the existing drainage projects so that, for example, the duration of flooding at Kamsack for the 1:500 year flood event was reduced by one day.

In considering the applicability of the results of this report to the question of the impact of drainage in the Basin, the DFCC had several reservations. Again, the most fundamental concern was with the drainage area approach. By taking this approach, it is pre-determined that drainage will increase both peaks and volumes. However, the routing of the outflows from the drainage project areas to the locations of interest was seen as an improvement over the use of the drainage area transfer method alone. Thus, the results of the study are acceptable within the limitations of the approach taken. For the purposes of this Study, the 1983 report was limited by its scope both in terms of examining only organized drainage projects, not including the individual and unauthorized projects, and by its geographic scope, terminating at Kamsack, whereas this Study was also concerned with the areas contributing to Lake of the Prairies and downstream of Shellmouth Dam to the Qu'Appelle River confluence.

6.3.2.2 1984 PFRA Study

The second major report using the technique outlined above in the Basin was undertaken by the PFRA (Scott and Martin, 1984) for the PPWB as referred to in Section 4.4. Seven small watersheds in the Rural Municipalities of Churchbridge and Langenburg in Saskatchewan were the focus of the study. These watersheds included Smith Creek on the south to Blackbird Creek on the north, and five tributaries to either the Assiniboine River or Blackbird Creek which cross the provincial boundary between Smith and Blackbird creeks. This area contributes to the Assiniboine River immediately downstream of Shellmouth Dam. For each of the seven watersheds the objectives of the study were to:

1) Delineate the effective drainage area (area contributing to runoff in a year of average runoff) under (a) natural conditions, (b) post-drainage conditions to1981, and (c) future (maximum potential) drainage conditions; and

2) Estimate the effect of the 1981 level of agricultural drainage, and potential future drainage on design flood hydrographs at the Saskatchewan-Manitoba boundary.

The delineation of drainage areas was undertaken with the assistance of PFRA photogrametric experts and the use of air photos as well as National Topographic Series maps. Results are provided in tabular form in the report, which indicates that the seven watersheds have an average gross drainage area of 133 km^2, covering a range from 2.1 to 512 km^2. The average effective drainage area, under natural (pre-drainage) conditions determined for the seven watersheds was 19.1 km^2, ranging from 1.8 to 64 km^2. There seems to be a considerable variability in the hydrologic drainage efficiency of the watersheds as shown by the gross to effective natural drainage area ratios which vary from 1.2 to 10.9 with an average value of 6.6. According to the figures provided, no agricultural drainage had taken place up to 1981 in three of the watersheds, while the other four watersheds show that drainage to 1981 had, on average, doubled the natural effective drainage area. The final phase of the drainage area delineation exercise, the future drainage condition, indicates that a considerable potential for additional drainage exists within all but one of the watersheds, to the extent that the effective drainage area could be increased an average of five times the value under natural conditions.

The second phase of the study was the estimation of the effect of the 1981 level of agricultural drainage, and future drainage on design flood hydrographs at the Saskatchewan-Manitoba boundary. Of the eleven potential hydrometric stations in the vicinity from which to draw data for the study, only one was found to demonstrate the level of hydrologic similarity and length of record to be of any use in the analysis. The flood frequency analysis was therefore based on a forty-year record of data, 1941 to 1980, for Yorkton Creek near Ebenezer (Water Survey of Canada station number 05MB001). Flood peaks for both summer rainfall events and spring snowmelt events were analyzed separately. A "by-eye" fit of the plotted flood peaks was determined to be most applicable and the Three-Parameter Lognormal distribution was selected as to best approximate the by-eye curve. Since the magnitude of spring flood peaks was greater than those from summer rainfall, the spring runoff frequency distribution was chosen as the basis for subsequent analysis.

The Yorkton Creek design flood peaks for the 1:2, 10, 50, 100, and 500 return periods were transferred to the seven watersheds on the basis of a contributing drainage area ratio technique. The method for runoff volumes described in the May 1980 discussion paper by R. S. Pentland and accepted for use by the Prairie Provinces Water Board, was modified by PFRA in this study for application to peak flows. For each of the seven watersheds a frequency curve of transfer factors was developed. First, each of the three effective drainage area conditions (natural, 1981, and future) was expressed as a ratio to the effective drainage area for Yorkton Creek raised to the 0.7 power. The 0.7 exponent was based on a 1961 PFRA study (Durrant and Blackwell, 1961) in which peak flows were found to be proportional to the ratio of drainage areas raised to an exponent less than unity, 0.7 for the study region. The transfer factors thus derived were plotted at the 0.5 frequency point on log-normal probability paper, while the gross drainage area is plotted at the extreme, 0.001 probability point. The transfer factors for the 1:10, 50, 100, and 500 events were then obtained by linear interpolation between the 1:2 (0.5 probability) and 1:1000 (0.001 probability) events. By multiplying the design flood peaks derived for Yorkton Creek by the transfer factors, design flood peak estimates for each of the seven watersheds were developed under natural, 1981, and future drainage conditions.

Runoff volumes in each of the seven watersheds under natural, 1981, and future drainage conditions for the 1:2, 1:10, 1:50, 1:100, and 1:500 flood events were similarly estimated from a frequency curve of unit runoff depths for Conjuring Creek near Russell (Station 05ME005). The flood peaks were subsequently adjusted to account for differences in depressional storage and other hydrologic characteristics between the Study watersheds and the Yorkton Creek watershed. Design hydrographs were then developed for all seven watersheds, drainage conditions, and return periods using the adjusted peak flows, the estimated runoff volumes, and rising and recession limb shapes from hydrometric records of similar sized watershed in the vicinity.

As expected with the study method, the design flood peaks all show an increase, over natural conditions, with increased drainage conditions. However, again as the technique dictates, the amount of increase in peak values decreases for the less frequent events.

The study conclusions recognized that the approach taken in the study does not account for road crossings of the streams in the study watersheds and that those crossings likely provide significant reduction of peak flows due to limited capacity and temporary storage of flows upstream of the crossings. The study also recommended that a program to collect hydrometric data in the watersheds be initiated and that development of drainage works in the watersheds be monitored and documented.

One specific concern with this study was the selection of Yorkton Creek as the station from which to transfer peak flows. Transfer of data from a watershed the size of the Yorkton Creek watershed compared to the seven study watersheds, a factor of over 100 in some cases, can be questioned. Additional concerns with this study surround the validity and significance of the numerous adjustments to the peaks and volumes of the calculated watershed hydrographs. The documented rationale for these adjustments was difficult to follow, thereby making replication of the study for these seven watersheds difficult, and application of the technique to other watersheds virtually impossible.

In considering the applicability of the results of this report to the question of the impact of drainage and land use change in the Basin, the DFCC had several reservations. The most fundamental concern was with the drainage area approach. By taking this approach, it is pre-determined that drainage will increase both peaks and volumes. The DFCC felt that while this result may indeed be correct, an approach was needed for the Study which addressed some of the weaknesses of the drainage area approach outlined in Section 6.3.1.

6.3.3 Summary

The drainage area technique for assessing the question of the impact of drainage in the Basin has limitations as outlined in Section 6.3.1. In addition, the approach does not address the question of the impact of land use and land cover changes on the hydrologic response of the Basin.

To apply this method, it would be necessary to identify all authorized or unauthorized private drainage works in the Basin, and to delineate the effective drainage area for each under current drainage conditions. It would also be necessary to define the pre-drainage effective area, either mapping it from early original air photos or by assuming area delineations done for previous studies do indeed represent pre-drainage conditions. As discussed in Section 5.4, data limitations preclude the identification of drained wetlands in the Basin, so application of the drainage area approach was not possible in this Study.

While the DFCC concluded that this technique was not applicable for the purposes of this Study, it did recognize that this approach has been and will continue to be routinely used for assessment of small watershed projects.

6.4 Storage and Hydraulic Routing Analysis Techniques

This section will examine two types of techniques used to route floods or runoff from one location in a watershed to some downstream location. When a flood flow moves down a stream channel, it is subject to a number of processes and forces which usually result in the hydrograph peak getting smaller, referred to as attenuation, and the duration getting longer.

6.4.1 Routing Methods and Models

In most cases, the dominant process is temporary storage of water in the stream channel, in lakes and ponds along the channel, and, in the case of higher floods, on the floodplain adjacent to the stream. Routing techniques that are based on variations of the conservation of mass equation are referred to as storage routing techniques.

In some situations, the dominant process is the force of gravity acting on the water, and the resistance of the stream bed and obstacles in the channel to the motion of the water. Routing techniques to assess this situation are based on the conservation of energy equation and are referred to as hydraulic routing techniques.

The simplest case of storage routing is that of a lake or pond where the outflow from the lake depends only on the level of water in the lake. In this situation, a simplified version of the storage routing technique is applied, referred to as level-pool routing.

Other methods of increasing complexity are the Puls method, Modified Puls, and Muskingum methods. Each accounts for the in-channel storage as flow and depth of flow increases. Each method requires an inflow hydrograph at the upstream end of the channel reach and assumes no inflows or losses along the length of the channel.

Calibration of the parameters required for these methods is possible only where there are measured or known flows at both the upstream and downstream ends of the channel reach and there is little or no local inflow or losses.

Storage routing is the more widely used of the two routing techniques. Numerous commercial and research computer models have been developed which incorporate both storage and hydraulic routing options. Two widely used commercial models are SSARR and HEC-1. The SSARR model routes flows by simulating channels as a series of level pools. The HEC-1 program has several channel routing options including the Muskingum and Modified Puls methods. The research model, Minnesota Model for Depressional Watersheds (MMDW), routes flows through depressional water bodies using the level pool method. Ducks Unlimited Canada and Manitoba Water Resources use a routing model, SIMPAK, originally developed at the University of British Columbia, which also uses the level pool method to route flows.

The mathematical equations which describe the process of a flood wave moving down a stream channel are quite complex. However, in many situations, some simplifying assumptions can be justified. Once these simplifications are made, there are two methods of hydraulic routing commonly used, the Kinematic Wave routing method, and the Muskingum-Cunge method. The Kinematic Wave method translates the flood wave down the stream channel but the simplifications do not allow for the normally observed attenuation of the flood peak and broadening of the base of the hydrograph.

For complex situations with varying inflows, a number of commercial and research models have been developed to solve the hydraulic routing equations. One widely used commercial model is HEC-1. The HEC-1 program has several hydraulic channel routing options including the Muskingum-Cunge method. The research model, Minnesota Model for Depressional Watersheds (MMDW), uses the Kinematic Wave method to route flows along stream channels.

6.4.2 Application of Routing Methods

6.4.2.1 Applications in the Great Plains

The MMDW has been applied to two small watersheds in Minnesota (Moore and Larson, 1980). The model has four major components which simulate the accumulation and melting of snow, the movement of water over and through the soil profile, routing of surface and subsurface runoff

through depressional wetlands and drainage works, and finally routing the resulting flows down the main channel. Level-pool routing is used to simulate the outflows from the depressional wetlands. Kinematic Wave routing is used to route flows in the main channel.

The two watersheds in Minnesota were 20 km^2 and 44 km^2 in surface area. Results for annual volumes show that the increased runoff volume following drainage is largely accounted for by the reduced evaporation from the drained wetlands versus the undrained wetlands. Annual drained volumes are not dependent on the type of drainage system (surface vs. tile).

Another finding was that improvements to the main channel alone, without draining any depressional wetlands, can dramatically increase peak flows and reduce duration of high flow. The authors say, "the effect on peak flows of enlarging and straightening the main drainage channel is much greater than the effect of draining individual depressions without main channel improvement."

6.4.2.2 Applications in the Basin

There are three examples of the use of hydraulic routing applications in the Basin. The first, by Harrison (1986), used Muskingum Routing to assess the effect of increased peak flows due to drainage in the RMs of Churchbridge and Langenburg on the Assiniboine River downstream of Shellmouth Dam. He found that the increased runoff from those RMs occurred prior to the main peak flow from the upper portion of the Assiniboine River basin. Thus, they had minimal impact on flooding in the Assiniboine River valley below Shellmouth Dam because of the large channel capacity of the River relative to the peak flows of the tributaries entering the River below Shellmouth Dam. The increase in duration of flow from the drained areas in the two RMs was also found to have no impact on agricultural flooding in the valley as they occur prior to the agricultural growing season.

Another study was by Fahlman and Banga (1991). Their study on the Yorkton Creek flood peak potential provides peak flow estimates for Yorkton Creek near the City of Yorkton with due consideration to the attenuating effects of the Yorkton South Complex. Inflow hydrographs were determined at several locations in the Basin using drainage area transfer from Yorkton Creek near Ebenezer (05MB001). Willow Brook at Willowbrook (05MB005) was considered, however, the report states that high flows bypass the streamflow station making it unsuitable for peak flow determination. A review of capacities and operations of the Yorkton South Complex revealed that it had, at most, only a negligible effect on the recorded peak flows of Yorkton Creek. The SSARR model was used to route the flood hydrographs to the watershed outlet while incorporating the effects of diversions and reservoirs. The study found that peak flow of Yorkton Creek largely occurs from runoff downstream of the Yorkton South Complex.

The third application of a model with a routing component was by Bell and Martin (1991). They used the HEC 1 model to determine the probable maximum inflow hydrograph to Shellmouth Dam. One component of the HEC 1 model transforms the precipitation inputs into runoff, while a second component routes the surface runoff through the stream channel network. The basin

above Shellmouth Dam was divided into four sub-basins: the Whitesand River to Canora, the Assiniboine River to Kamsack, the Shell River to Roblin, and the Assiniboine River to Shellmouth Dam. In this application, the Modified Puls channel routing was used to route sub-basin hydrographs into Lake of the Prairies.

6.4.2.3 Application to Wetlands

Level-pool routing could be used in a conceptual consideration of the effect of a simple wetland drainage project. To determine the effect of the project on outflows from the wetland area, this routing technique would be used to examine the two cases: the natural wetland, and the drained condition. In this approach, the inflow to the wetland area is assumed to be the same in both cases and one or more design inflow hydrographs may be examined. In examining these cases, the assumption made concerning the initial water level in the wetland at the beginning of the inflow event is important.

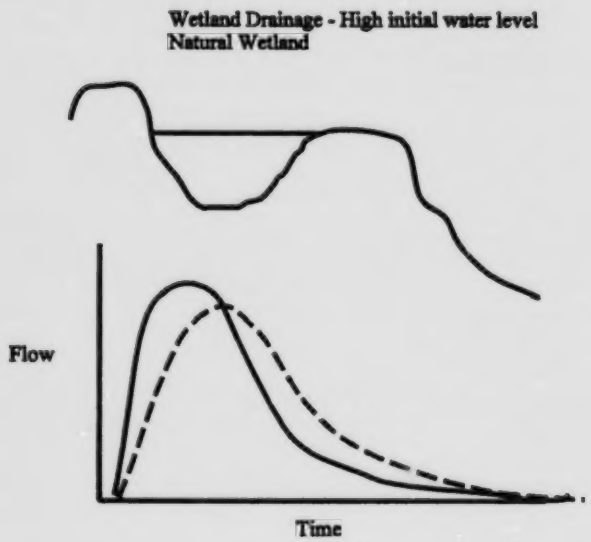
The following series of figures illustrate on a conceptual level the effects of drainage under various conditions. Figure 6.13a shows a cross-section of a natural wetland, with its surrounding upland shown as the high ground on the left and its overflow to the right. In Figure 6.13a, it is assumed that the natural wetland is full at the beginning of the runoff, perhaps due to an extremely wet fall the previous year. Inflows over time are shown as the solid line, outflows as the dashed line. Because the wetland is full, outflows begin almost immediately after inflows enter the wetland. The peak outflow is only slightly reduced, with the magnitude of the reduction depending on the discharge characteristics of the natural outlet. The total outflow volume equals the inflow volume.

Figure 6.13b shows the same wetland. However, in this case a drainage outlet has been developed. With the drainage outlet in place, the initial water level of the wetland will be low, even if the previous fall had been wet. For the same inflow as in Figure 6.13a, the outflow hydrograph will be much the same as for the natural condition, with the only differences due to the differences in the discharge characteristics of the natural outlet compared with those of the constructed outlet. Again, the total outflow volume will equal the inflow volume. In this case, drainage has no impact on the outflow volume from the wetland, and little effect on the peak flow and timing of the peak flow.

Another, perhaps more common situation is shown in Figure 6.14a where the natural wetland has little or no water in it at the beginning of the runoff event. Depending on the volume of the inflow compared to the storage volume available in the wetland, only a small outflow may occur as shown in Figure 6.14a under natural conditions. No outflow will occur if the available wetland storage is greater than the inflow volume. In either case, the outflow volume is much less than the inflow volume. If outflow does occur, it does not begin until well after the inflow has begun. Also the peak outflow will be much less than the peak inflow and will occur later. By way of contrast, Figure 6.14b shows the same wetland but with a drainage outlet. For the same inflow hydrograph as in Figure 6.14a, the drained wetland will have a much higher peak outflow, it will occur closer to the inflow peak, and the outflow volume will equal the inflow volume. Thus, in this situation, drainage will increase the peak outflow, increase the outflow volume, and advance the timing of the outflow peak relative to the natural situation.

Figure 6.13
Wetland Drainage - High Initial Water Level Scenario
(Inflow - solid line, Outflow - dashed line)

a)



b)

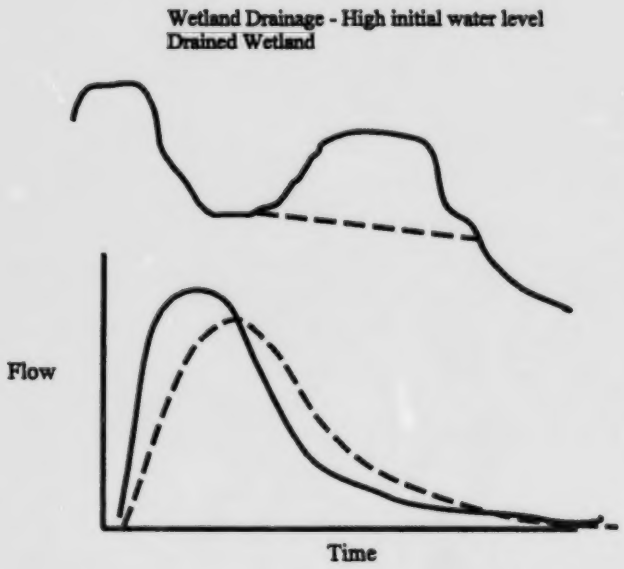
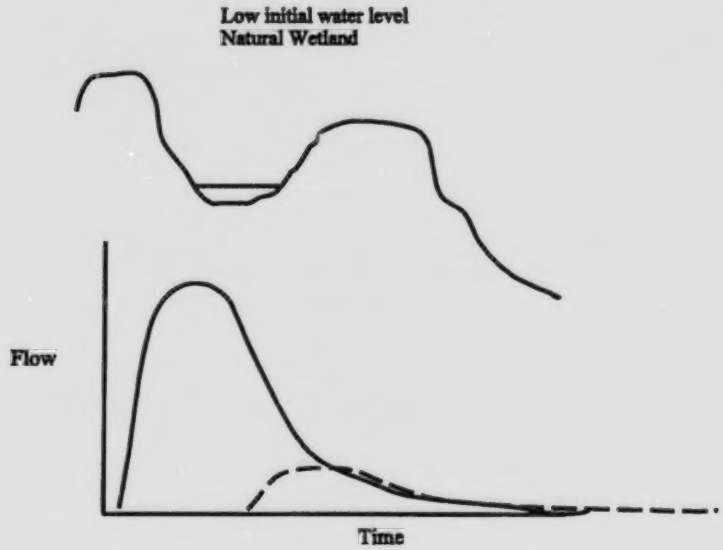
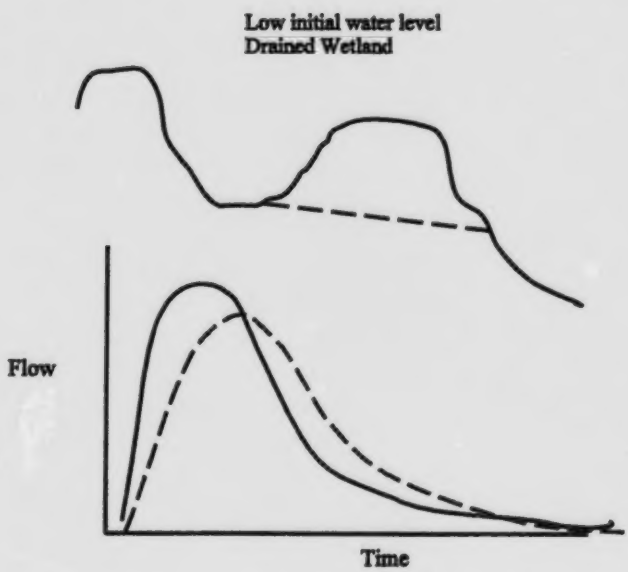


Figure 6.14
Wetland Drainage - Low Initial Water Level Scenario
(Inflow - solid line, Outflow - dashed line)

a)



b)



Further outflow situations can be anticipated if a culvert is constructed in an embankment across the outlet ditch, as shown in Figure 6.15a. Proper design of the embankment would have the top higher than the natural overflow level of the wetland and at least a portion of the natural overflow would be retained as an emergency spill section for situations where the inflow rate and volume exceeds the capacity of the culvert. (A road embankment with a culvert(s) immediately downstream of the wetland may have a similar effect). The outflow hydrograph shown in Figure 6.15a shows that outflow rates quickly reach the culvert capacity and remain at that rate until the volume of the inflow has been discharged. This assumes that the inflow volume is not so large as to cause the wetland to overflow. In this case, for the same inflow as shown in Figure 6.14, the peak outflow is reduced from that shown in Figures 6.13b and 6.14b. However as the same volume of water is discharged, and the duration of the outflow is longer. In Figure 6.15b, the inflow hydrograph volume exceeds the capacity of the wetland storage. The outflow hydrograph is the same as in Figure 6.15a except that the overflow spill is added, increasing the maximum outflow and reducing the duration of the outflow hydrograph by the length of time that would have been required to discharge the spill via the culvert alone.

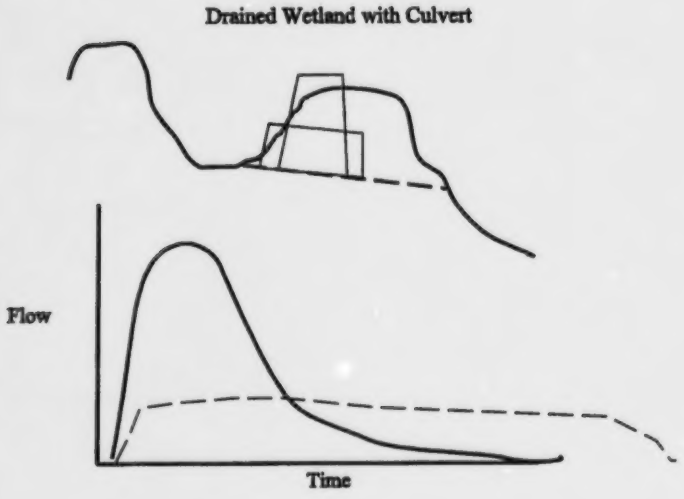
In Figure 6.16, a control gate is placed on the culvert, allowing the discharge to be regulated. If the control gate remains open from the onset of inflow, the discharge hydrographs will be identical to those shown in Figure 6.15. The outflow hydrograph from a regulated wetland will be similar to that shown in Figure 6.15 except that the culvert discharge may be less than the culvert capacity and the discharge from the culvert may be delayed and/or interrupted for any variety of reasons. It must be remembered, however, that most landowners and drainage authorities undertake drainage works to speed the removal of water from the land.

To move from the conceptual analysis presented above to a practical situation requires the collection of topographic data from the wetland and design plans for the drainage works in order to apply a level-pool type of routing analysis. Also required are inflow hydrographs and assumptions concerning the initial water level in the natural wetland at the onset of the runoff event being analyzed. The wetland topography is used to determine the storage-elevation relationship of the wetland and the elevation-discharge relationship of the natural overflow. The design plans for the drainage works are used to determine the elevation-discharge relationship of the outlet of the drained wetland. Once all this is in place, the effect of the specific project on that specific wetland can be assessed for the inflow hydrographs and initial natural water levels used.

In the example being considered, once the effect of the drainage works on the outflow from the wetland has been determined, the outflows must then be routed down the stream channel network to various points of potential impact or concern. Downstream points of concern may include road culverts and bridges, low-lying farmland adjacent to the stream, sections of stream bank susceptible to erosion, downstream reservoirs intended to hold and discharge any additional flow, etc. If the issues to be addressed primarily involve flow rates at a downstream point, the storage routing models discussed earlier may be sufficient. If more detailed information is required, an hydraulic model will need to be used to provide estimates of water levels and flow velocities at various downstream points. Both types of models require extensive slope and cross-section data for each reach of the stream. However, the hydraulic routing models do require more data than do the storage routing models.

Figure 6.15
Wetland Drainage - Outlet with Culvert Scenario
(Inflow - solid line, Outflow - dashed line)

a)



b)

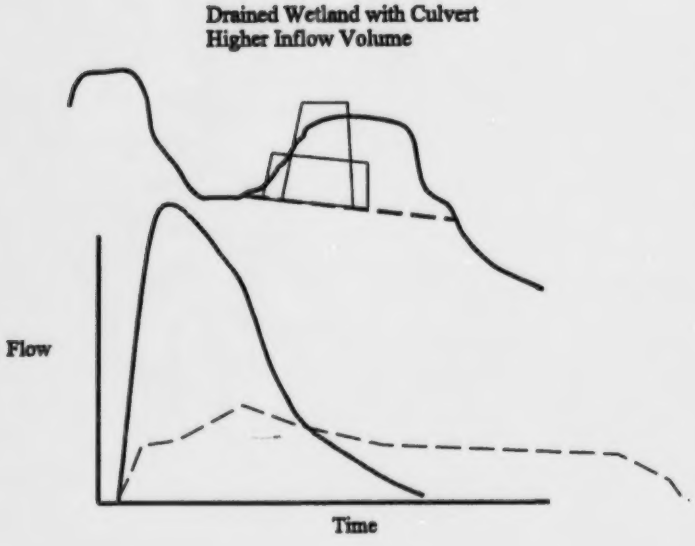


Figure 6.16
Wetland Drainage - Outlet with Gated Culvert Scenario

Whiteley (1979) reviewed the effects of drainage on peak flows and volumes. He found that the effect depends on the extent of drainage in the watershed, whether the entire watershed has been subject to drainage works, or only portions of it. "If the drainage in an entire watershed is speeded up the peak flood flowrate will be higher...", he notes however that, "if a small portion of a watershed has altered drainage, the effect at the downstream end of the watershed will be small. In some cases the effect may even be to slightly reduce flood peaks if the drainage works separate the time of occurrence of peaks from different parts of the watershed which were previously synchronous." In the Basin, Harrison (1986) found that the increased runoff from the RMs of Churchbridge and Langenburg due to drainage projects occurred prior to the main peak flow from the upper portion of the Assiniboine Basin. The study by Moore and Larson (1980) discussed earlier, had also noted the relative importance of the effects of channel improvements on the timing of flows and consequently on downstream flow rates and water levels.

Whiteley (1979) goes on to note that the effect on flooding downstream depends on the capacity of the receiving channel network. He writes, "... the peak flood water level is often relatively unchanged because the increase in flowrate is balanced by an increase in channel capacity. The most observable result is a decrease in the length of time a particular water level is exceeded. The most conspicuous effects of drainage on downstream flood peaks will be observed when upstream portions, covering a large proportion of the watershed, have drainage significantly speeded up while the downstream channel is left in its natural condition."

6.4.3 Summary and Conclusions

This section has examined the streamflow routing approach to address the question of the impact of drainage of a single wetland on downstream flows and water levels. Routing methods are used primarily in the design and analysis of wetland drainage and channel improvement projects on a small watershed scale. They can not be used to assess the impact of land use and land use changes on the hydrologic response of a watershed. Routing techniques are data intensive. For this reason most applications are for individual projects in smaller watersheds. The use of routing techniques requires either that the inflow hydrograph(s) be generated with some other technique or be assumed. In comparing the effect of wetland drainage to natural conditions, important assumptions need to be made on the initial water level of the natural wetland. Previous applications and discussions of routing models have found that general statements on the effect of drainage are difficult to make. The only general statement that can be made with certainty is that drainage will increase flow volumes in most years but not all years. General statements on the effect of drainage on peak flows and timing of peak flows can not be made because the effect depends on a number of site-specific, project-specific, and watershed-specific factors.

A routing approach was not taken in the Study for the following reasons:

- It would not address the question of the impact of land use and land use change on the Basin hydrology.

- No information exists on the location and physical characteristics of the many individual private drainage projects, their outlets and downstream conveyance works. Acquisition of the necessary data to properly assess the impact of these projects was not possible in this Study.

- Even if the impact of each individual drainage project could be properly determined, the cumulative effect on the magnitude and timing of peak flows at locations of concern would require development and calibration of a computer routing model for the Basin.

- Selection of appropriate initial wetland water levels under natural conditions to provide meaningful assessment of drainage would require development and application of a hydrologic model for the Basin to facilitate proper consideration of year-to-year carryover storage in the wetlands.

This analysis, however, does point out the benefit of having drainage works capable of regulating outflows.

The DFCC recommends the construction of backflood projects and the use of outflow control mechanisms on wetland drainage projects to prolong outflow duration at reduced flow rates. These would permit the soils to thaw and increase infiltration. Such projects hold water upstream, lengthen the period of runoff and reduce the risk of flooding downstream.

6.5 Vertical Water Balance Method

The concept of the vertical water balance method examines the hydrologic processes within a vertical column extending from the surface of the groundwater table up to the top of the vegetative canopy above the surface of the ground. The amount of water which enters this column from the top, as either snow or rain, is tracked through the various physical processes as it makes its way through the column. It may be stored at various locations within the column, or it may exit the column either through evaporation, transpiration, surface runoff, inter-flow, or groundwater movement.

Recent advances in hydrologic techniques for the prairies have produced a generation of hydrologic computer models that consider the spatial variability of the physical processes, input, boundary conditions, and watershed characteristics. These new models are termed 'Distributed Models' because of their capability to simulate the spatial distribution of the variables and parameters. These models generally have two basic components. The vertical water balance component considers a unit of area of the watershed. A routing component tracks the surface runoff, inter-flow, and in some models, the groundwater movement, from each unit of area to the outlet of the watershed. Several of the models discussed in the previous section on routing also have vertical water balance elements.

The DFCC decided that the application of a distributed hydrologic model would be the best method to analyze the effects of agricultural land changes on streamflow in the Basin. The intended approach involved the configuration of the selected hydrologic model in two unique situations, one representing the land cover conditions in the pre-drainage period, accepted for the purpose of this Study, as the 1950s, and the second representing the present day setting of the Basin physiography.

Once the physical land cover distributions for the two eras had been established, both scenarios could be modeled to simulate the application of the same meteorological inputs from some past flood event (i.e., precipitation, temperature, radiation, dew point temperature, etc.). The resulting hydrographs would be compared. It was anticipated that the comparison of the resulting hydrographs for different watersheds within the Basin and for several runoff events would distinguish the effect of the changes in land cover from the effect of drainage.

6.5.1 Model Search

Once the Study approach was agreed upon, the next step was to locate potentially suitable models to review and then select the one most appropriate for the Study. The search for distributed hydrologic models was initiated by listing those models that were known to the DFCC members and contacts. This was followed by literature and Internet searches. As likely models were identified, as much pertinent information as could be found was acquired to aid with the evaluation process. Initially, 15 models were selected for further review, most of which are discussed in Singh (1995). The 15 models initially selected were:

1 - Agricultural Engineering, University of Natal Model (ACRU);
2 - Coupled Hydro-geomorphic Model (CLAWS);
3 - Guelph All Weather Sequential Event Runoff Model (GAWSER);
4 - Hydrologic Prairies System (HMS) - Revised version of the U.S. Army Corps of Engineers HEC-1;
5 - Hydrological Simulation Program - FORTRAN (HSPF);
6 - HYDROTEL;
7 - Fourth generation model, Système Hydrologique Européen (MIKE SHE);
8 - Minnesota Model for Depressional Watersheds (MMDW);
9 - Object Watershed Link System (OWLS);
10 - Simple Lumped Reservoir Parametric (SLURP);
11 - Snowmelt Runoff Model (SPM);
12 - Soil and Water Assessment Tool (SWAT);
13 - TOPMODEL;
14 - TR-20 - U.S. Soil Conservation Service Model; and
15 - Flood Forecasting System (WATFLOOD/SPL7).

6.5.2 Model Selection

6.5.2.1 Criteria

The evaluation of the candidate models initially required the development of guidelines by which they would be compared. The DFCC devised a list of model criteria based on the work requirements and the data available for the Study. These criteria, or model characteristics, served as the guidelines to determine the most suitable model to conduct the analysis. Following is a list of the required model features, including a brief description and some discussion of the importance of the specific criteria relevant to the Study.

(1) Continuous

A 'Continuous' model is one which may operate continuously over several days or many months or even years, as required. Alternatively, 'Event' based models are designed to operate on a short term, single event basis and thus are capable of covering only a relatively short period of time, such as a few weeks to a month or two. The model selected for the Study must be able to simulate continuously, over a long period of time, to primarily overcome possible bias that could be introduced by not including the appropriate antecedent conditions. Antecedent condition refers to the state of soil moisture, available wetland storage, and snow cover accumulation and distribution prior to spring runoff. Activities such as tree and brush clearing, land use practices, and wetland drainage have a distinct effect on the antecedent conditions. Therefore, it was felt that it was necessary to simulate for one or more years, as opposed to only a few days or weeks, on either side of the runoff event.

(2) Distributed or Semi-distributed Models

As previously described, the term 'Distributed,' in the context of hydrologic prairies, implies that the model accommodates spatially distributed input and output data, as well as physiographic

basin description information. However, most models are described as 'Semi-distributed' because they are designed to use 'lumped' input for discreet sub-basin units. Some of the hydrologic processes and some of the basin characteristics are lumped or averaged in the analysis procedure. In these cases the processes that are directly linked to the rainfall-runoff (or snowmelt-runoff) outputs are distributed. Semi-distributed models have the advantage of incorporating the necessary physics while retaining simplicity of operation. There are few purely distributed models and those that do exist are impractical for most prairie watersheds since they require highly intensive data and thus tend to be cumbersome. For that reason it was decided to consider semi-distributed models as well.

(3) Snowmelt Runoff

Virtually all hydrologic models that might be considered for the Study synthesize the physics necessary to convert meteorologic input, in the form of rainfall, to simulated streamflow runoff. An absolutely essential component of the model, for the Study, is the capability to simulate snowmelt utilizing standard available meteorological data. There are predominantly two types of snowmelt routines used in prairies. The 'degree-day' routine is the simplest to use and is based on either mean daily or maximum daily temperatures. The 'energy balance' routine depends on a balance of incoming and outgoing energy to arrive at the energy available for melting snow. The energy balance approach requires more data than the degree-day technique. Furthermore, the type of long and short wave radiation data required for energy calculations is not available from as many stations or for the long periods of record compared to temperature data which is relatively much more abundant. In the model selection process, models which had only the energy budget snowmelt routine were not considered as favourably as those employing the degree-day technique on the basis of data availability and requirements as the intention was to simulate the Basin for the 1950s when such data was not available.

(4) Wetland Storage

The term "wetland storage" was adopted to avoid a minor semantic problem that would have occurred from the use of the term "depressional storage," which is primarily used in hydrology to describe the portion of rainfall that is intercepted by small pools and depressions and thus prevented from becoming part of runoff. Wetland storage is the expression used to describe the total available 'reservoir storage' of the small, shallow, intermittent prairie water bodies. Their drainage is one of the central issues of the Study. Thus, it is imperative that only hydrologic models designed to analyze basin runoff, that simulate the temporary storage of overland flow in surface depressions, sloughs, and marshy wetlands, would be considered. Wetland storage and depressional storage differ in size, retention time and overall quantitative significance, the latter being, in effect, small puddles retaining water for a day or two at most, before being dissipated through a combination of infiltration and evapotranspiration. Several models referred to their incorporation of depressional storage in just that sense but made no allowance for the much more significant storage component represented by larger naturally occurring water bodies like the prairie wetlands that abound in the Basin. Such models did not qualify for application to this Study.

(5) Channel Routing

The model must be capable of transferring flows from point to point or from incremental area to area according to an accepted channel routing technique. It was agreed that a simple hydrologic or hydraulic channel routing routine would not be adequate because drainage projects may complicate things by altering channel conveyance and travel times. Most models had more sophisticated and complete channel routing routines such as the Kinematic Wave, Muskingham-Cunge, and the Saint Venant Equation. However, the Saint Venant Equation technique was ruled out for use due to its excessive data requirements.

(6) Channel Configuration Changes

Channel configuration changes refers to the system within the model which identifies the flow paths from one incremental area to the next. In many models this is handled by a geographical information system (GIS) vector diagram. The important aspect for application to the Study is that the system can be easily altered to reflect Basin drainage changes predominantly due to wetland drainage.

(7) Vertical Water Balance

The prairies process must take into account the vertical movement of water. Thus, some provision is made for a portion of the surface water to infiltrate into the soil as a function of the soil type and level of soil moisture. Infiltrated water can remain in the soil or percolate deeper, eventually becoming groundwater. Under other conditions soil moisture is able to move upward and to either become surface flow as spring water or be passed on to the atmosphere through the process of evaporation or transpir tion.

(8) Evapotranspiration

The selected model had to account for the quantity of water lost to the atmosphere through evaporation and transpiration. Several acceptable evapotranspiration formulae are available. Some such evapotranspiration techniques, named for their respective originators, are the Penman, Monteithe, and Morton methods. Another technique is called the potential evaporation routine which uses pan evaporation data.

(9) Overland Routing Routine

Similar to channel routing, overland routing refers to the transferring of flows from point to point, but in this case the flows in question are overland flows and are not necessarily confined to a channel. Acceptable models had to incorporate some reasonable hydraulic flow routing technique such as the Manning equation or the Kinematic Wave flow routing routine.

(10) Parameter Optimization

Many of the models, recently developed, include a 'built in' parameter optimization or 'automatic calibration' routine. Use of a parameter optimization routine simplifies the model calibration process for users who may be unfamiliar with the model parameters and the sensitivity of those parameters within the context of the model operation. Although many practitioners agree that automatic parameter estimation procedures have not yet matured to the point that they can entirely replace manual methods, they can often speed up the calibration

process. Since the DFCC recognized that some of the required physical parameters would be unavailable for the Basin and that those charged with the responsibility of conducting the actual prairies task would initially be unfamiliar with the selected model, it was decided to include a criterion requiring that the models considered for final selection must have some form of a parameter optimization routine.

(11) Documentation

The successful application of any sophisticated software tool is limited by the amount of detailed, documented information describing the complexities of its composition, use, and limitations. The term, documentation, as used in the context of this Study, is not limited to the written word, but also implies the availability of informed resource people to aid in understanding the intricacies of the model. The importance of the Study and the high degree of complexity necessitated by the type of computer models being considered made the availability of model support, as well as comprehensive printed reference material, a very high priority consideration in the model selection process.

In addition to the foregoing criteria some additional features considered desirable in the selected Study model were identified, as follows:

- A geographical information system (GIS) interface;
- Flexibility in output times steps; and
- Documented indication of successful previous applications.

Implicit to the overall model selection process was the stipulation that the selected model be the simplest model that will do the analysis.

6.5.2.2 Selection

Models of the sophistication and complexity required for the work of the Study are very time and labor intensive. This aspect precluded conducting a series of test runs with each of the models to assess and compare their performance. The evaluation procedure utilized a literature review process. All available information obtained for each of the candidate models was screened in order to assess how well the candidate models met each of the required Study criteria. Documented information was augmented, where possible, through direct contact with model users and, in a couple of instances, contact with the model developers. Despite efforts to obtain as much pertinent reference material as possible for each of the candidate models, information for most of the models was limited and, in some cases, almost nonexistent. Even where substantial documentation was available, important model details were often obscured, to the point where it was not evident what specific techniques were employed by the model.

The results of the review process are summarized in Table 6.10. This summary table provides an abbreviated format for the comparison of the content and capability of the various models. In many cases a simple "yes" or "no" was used to indicate simply whether or not the model accommodated a particular criterion in some form or another. Where significant approaches,

techniques, or formulae were employed they were noted in the table using the term commonly referred to in current technical literature. Question marks indicate those criteria where information was either unavailable or unclear.

The DFCC attempted to identify all proven existing distributed and semi-distributed hydrologic models which might be potentially used for the Study. It is likely that some pertinent knowledge or valuable contact was overlooked despite the effort that went into acquiring the available information on the 15 candidate models that were selected for evaluation. Further, it is possible, during the course of the evaluation process, that some aspects of the models may have been misrepresented due to ambiguities within the information that was obtained. Finally, since hydrologic models tend to be in a dynamic state of constant revision and improvement, some of the models which were excluded may now be suitable for the Study.

The summary table of model attributes was carefully scrutinized in a process of elimination. Two models, CLAWS and OWLS, were immediately rejected due to a lack of information. Further examination of the tabulated attributes resulted in the elimination of the models ACRU, GAWSER, HMS, SRM, SWAT, TOPMODEL, TR20, and WATFLOOD since they did not meet the essential requirements. In most cases these models were eliminated because they were not continuous, did not have snowmelt simulation capabilities, or did not consider wetland storage. The HSPF model was rejected because there is insufficient data available for the Basin to carry out energy budget calculations for snowmelt. Although the Minnesota model, MMDW, showed some initial promise, it was later rejected because it was not intended for large watersheds. Also, no evidence could be found to indicate that the model had ever been updated or that it was even still available. At the conclusion of this exercise, three models that met the essential criteria remained: HYDROTEL, MIKE SHE, and SLURP.

After further consideration the MIKE SHE model was eliminated because the limited amount of data available for the Basin would not support the application of a model with such a high data requirements. In the end, it came down to the available support for model application. This resulted with the selection of the SLURP model over HYDROTEL.

The SLURP model was developed locally at the National Water Research Institute (NWRI) in Saskatoon. The staff at NWRI were willing to provide assistance to the configuration and application of the SLURP model to the Basin. Furthermore, meetings could be easily attended by all parties.

Table 6.10 - Model Selection Summary Table

Model Selection Matrix - UARB Study

Models	Criteria										
	Continuous Model	Distributed Model	Snowmelt Routine	Wetland Storage	Channel Routing	Channel Config. Changes	Vertical Water Balance	Evapo-transpiration	Overland Routing Routine	Parameter Optimization	Documentation
ACRU	Yes	Semi	No	No	Yes	No	Yes	Yes	No	No	Poor
CLAWS	Yes	Yes	?	?	Yes	External	Yes	Penman-Monteithe	Yes	No	Poor
GAWSER	Event	Semi	Degree Day	Implicit*	Muskingum	External	Yes	Linacre	No	No	Fair
HMS	Event	Semi	Degree Day /Energy Budget	Implicit*	Hydrologic /Hydraulic	No	No	No	No	Yes	Good
HSPF	Yes	Semi	Energy Budget	Implicit*	Kinematic	No	Yes	Yes?	Kinematic	No	Good
HYDROTEL	Yes	Yes	Degree Day ?	Yes	Yes	Labour Intensive	Yes	3 Methods	Yes	Yes	Good
MIKE SHE	Yes	Yes	Degree Day /Energy Budget	Implicit*	Saint-Venant (Simplified)	Preprocesser Software	Yes	Penman-Monteithe	Saint-Venant (Simplified)	No	Good
MMDW	Yes	No	Energy Budget	Yes	Kinematic	Yes	Yes	Basis Potential Evaporaton	No	No	Poor
OWLS	Yes	Yes	?	?	?	?	?	?	?	?	Poor
SLURP	Yes	Semi	Degree Day /Energy Budget	Implicit*	Channel Lag /attenuation	Vector in GIS	Yes	Morton	Manning	Yes	Good
SRM	Yes	Semi	Degree Day	No	No	No	No	No	Yes	No	Good
SWAT	Yes	Yes	Degree Day	No	Yes	No	Yes	3 Methods	No	No	Poor
TOPMODEL	Yes	Yes	No	No	Constant Wave Speed	Vector in GIS	Yes	Basis Potential Evaporation	No	No	Poor
TR20	Event	No	No	Yes	Yes	No	No	No	No	No	Poor
WATFLOOD	Event	Semi	Degree Day	Implicit*	Manning	Vector in GIS	Yes	Yes?	Manning	Yes	Poor

* Implicit means that wetland storage may be represented as a small reservoir, or by adjusting the upper zone storage function.

7 Hydrologic Modeling

7.1 Model Development and Upgrades

Early in the Study, a process was initiated to select and apply a hydrologic model to simulate the watershed and attempt to address issues surrounding the hydrologic impacts of agricultural drainage and land clearing in the watershed. Such a model was also envisaged as a tool which would be maintained and applied to assist in water management decision-making subsequent to the Study. After considering the types of models available, as discussed in Chapter 6, the Committee concluded that a vertical water balance type model would be most appropriate for this application. After examining 15 hydrologic models, the Committee selected the National Water Research Institute's (NWRI) SLURP model.

The NWRI model is the result of many decades of hydrologic research and development based primarily out of the National Hydrology Research Centre located in Saskatoon. Despite the Centre's location in the Canadian Prairies for some 15 years, to date there has been no successful application of the SLURP model to a large watershed in the Canadian Prairies. However, it should be noted that none of the other hydrologic models examined by the DFCC have been successfully applied to the Canadian Prairies.

The DFCC requested that NWRI make several upgrades to the SLURP model (Version 11) to better simulate hydrologic processes in the prairies. Three important upgrades were: 1) modifications to the winter evaporation and soil drainage routines, 2) wind redistribution of snow during the winter, and 3) infiltration of snowmelt into frozen soils. The upgraded version, named PBS-SLURP was completed by NWRI in March 1998 (Pomeroy *et al.*, 1998).

7.2 Data Compilation

7.2.1 Selection of Study Period

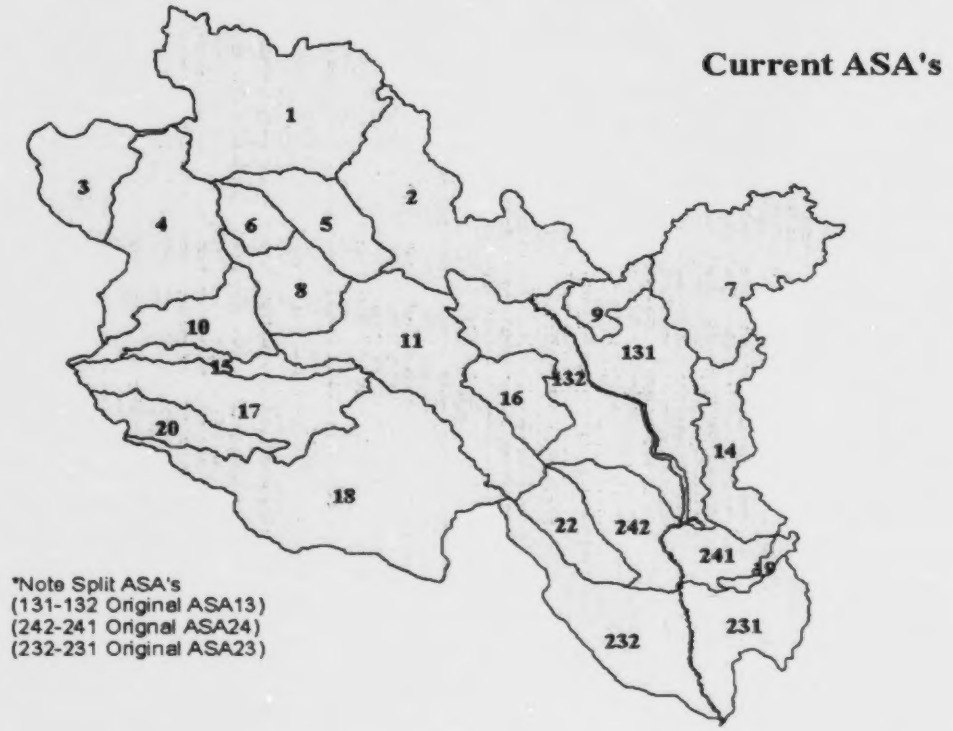
Two periods were originally selected on which to run the model; 1954 to 1957, and 1993 to 1996. When the study commenced, data were only available up to 1996. Meteorologic and hydrometric data were subsequently available for 1997. Both periods are characterized by high flow years, particularly 1954, 1955, and 1995. It was postulated that any difference in hydrologic response between these two periods would be attributed to changes in land cover in combination with drainage development in the intervening four decades, and not to the prevailing hydrologic/meteorologic cycle. For periods prior to the mid-1950s, hydrometric data in the Basin are scarce, as is mapping or aerial photography on which to determine land cover. It was hoped that with land cover data sets for each period, the effects of land cover changes and of drainage development could be quantified with the SLURP model.

7.2.2 Selection of Watersheds for Modeling Purposes

The Basin was divided into 25 watersheds for the purposes of modeling with the SLURP Model shown in Figure 7.1. These watersheds were defined at streamflow station sites, outlets of lakes or reservoirs, or at junctions of two or more streams. In the case of Lake of the Prairies and the lower portion of the Assiniboine River, the watersheds to Shellmouth Dam, Highway 16 crossing near Russell, and to the confluence with the Qu'Appelle River were split into two watersheds along the river. This was done so that the somewhat different topography between the east and west sides of the Assiniboine River would be preserved in the SLURP model. The numbering system that ultimately was used for the watersheds reflects the evolution of the technical GIS and Digital Elevation Model processes required to split the watersheds along the river.

The SLURP documentation refers to the watershed units as Aggregated Simulation Areas, or ASAs. In SLURP, ASAs do not necessarily have to be defined as watersheds; they can also be elevation bands in mountainous terrain or other areas of similar hydrologic response. Throughout the remainder of this report, the term "ASA" will be interchangeable with the term "watershed." Both will refer to the watershed units defined for the SLURP model.

Figure 7.1
Current ASAs



Below is a table listing the ASA number shown in Figure 7.1, the ASA name, and its area.

Table 7.1 - ASA Areas

ASA	ASA Name	Area (km^2)
3	Fishing Lake	634
4	WSR near Sheho	1,218
10	WSR to Theodore Reservoir	596
15	WSR to confluence with Yorkton Creek	253
20	Willow Brook	403
17	Cussed Creek	1,033
18	Yorkton Creek	2,323
6	Spirit Creek	260
8	Good Spirit Lake	565
11	WSR near Canora	1,471
1	Assiniboine R near Sturgis	1,927
5	Crooked Hill Creek near Canora	581
2	Assiniboine R at Kamsack	1,698
9	Little Boggy Creek	255
16	Stony Creek near Kamsack	456
7	Shell River near Roblin	1,329
14	Shell River near Inglis	666
131	Local area east of Lake of the Prairies	1,016
132	Local area west of Lake of the Prairies	1,129
19	Conjuring Creek near Russell	75.9
22	Smith Creek	439
241	Local area east side above Russell	402
242	Local area west side above Russell	588
232	Local area west side above St. Lazare	1,064
231	Local area east side above St. Lazare	771

7.2.3 Land Cover

SLURP is a vertical water balance model that represents basins and watersheds as having a variety of user-defined land covers. Each land cover has its own canopy, storage, infiltration, and runoff characteristics. Each land cover has the same characteristics across any number of ASAs that make up the entire basin being simulated. In order to determine the effect of land cover changes and the effect of drainage on hydrology in the Basin, it was necessary to have a set of land covers that were consistent and comparable in their definition between the 1950s and the 1990s.

Land cover data for the 1990s were available in the form of satellite coverage taken in 1994 and 1995 for the federal Western Grains Transportation Payment Program. This satellite coverage has 11 land cover classes and resolution to 30 m by 30 m pixels. A second data base, developed by Ducks Unlimited Canada, was also available. That coverage focused on various types of wetlands with less information about all the remaining covers in the Basin.

Two options were identified for obtaining land cover information from the 1950s: black and white aerial photography taken primarily in 1948 and 1949, or Edition 1 National Topographic System (NTS) maps at a scale of 1:50,000. Of particular interest for this study would be to detect changes in land cover representing drainage of wetlands and clearing of woodlands to bring land into agricultural production. A study commissioned by Sask Water in the 1980s had found that artificially drained land could not be determined at an acceptable level of accuracy using satellite imagery (Kallenbach and Banga, 1987), however it was felt that detection of change and drainage works might now be possible. The Saskatchewan Research Council and Trigon Mapping were contracted to undertake a pilot project to investigate alternative methods to detect drainage activity (Trigon and SRC1997).

In the Trigon/SRC study, initial activities focussed on establishing a comprehensive database for the pilot area in order to undertake automated change detection routines. Two landscape changes were thought to have the greatest impact on the Basin hydrology: the loss of water storage through drainage and land clearing. A variety of information sources was compiled, digitized where required, and analysed using a GIS. Among the key datasets were the digitized aerial photos from the 1950s and 1995, satellite imagery dating from the mid 1990s, and the digital 1:50,000 scale NTS maps (including the digital elevation model derived from the mapping). Through the analysis of these data, it was envisioned that the combination of image analysis software and GIS would enable the development of automated change detection routines. If drainage and land clearing could be accurately detected in the pilot area, the analysis would be extended to the entire Basin.

Unfortunately the pilot project did not yield reliable results. In particular, image analysis of the aerial photographs, especially the 1950s series, required manual verification primarily to detect bush cover (Trigon and SRC, 1997). A level of accuracy of 80 percent was not sufficient.

Although the development of automated routines to detect landscape change was not successful, the project did develop useful information for application during the Study. A variety of datasets was brought into the GIS environment and used for many purposes by the technical committees. Similarly the digital elevation model assisted the Study's hydrology work. And finally, the pilot study identified an alternative to scanning historical aerial photographs. It was noted that the first edition NTS maps for the Basin are based on the mid 1950s photos. Historical landscape conditions could be captured from that source.

The Edition 1 NTS maps have three colours to represent land covers; green for treed areas, blue for area covered by water, and white for all other covers combined. Of course, there are other features shown in other colors to depict roads, buildings, and urban areas, etc., however these make up a very small percentage of the land surface area.

SLURP has a routine to treat evaporation from large waterbodies differently from evapotranspiration from other land surfaces. Therefore, the water areas in both the 1950s and the 1990s coverages could be separated into two cover classes: large waterbodies termed "lakes", and smaller waterbodies, termed "wetlands." The classes were divided on the basis of surface area being either 100 ha or more, or less than 100 ha. The 100 ha criterion was selected in order to minimize the "edge effect" of evaporation from the large water bodies where evaporation is higher at the upwind side of the lake as drier air moves over the lake from the surrounding land environment.

Thus, four land covers could be determined from each of the two data sources: treed area, wetlands (less than 100 ha), lakes (100 ha or more), and everything else. A fifth land cover would be developed by comparing the wetland land coverage from the 1950s with the coverage from the 1990s. It was assumed that since both coverages represent wet periods, that any loss in wetlands from the 1950s to the 1990s would represent wetlands which had been drained.

As explained in the following sections, the Edition 1 NTS coverage turned out not to be compatible with the 1990s satellite coverage. This incompatibility removed any opportunity of developing a land cover class to represent drained wetlands. Without this land cover class, the SLURP model would not be able to determine the effect of drainage on Basin hydrology. The Trigon, SRC study had examined other means of detecting drainage but had found none that were technically and economically feasible.

With no historic land cover data available, there was no longer any requirement to limit the number of land covers from the 1990s to the original four. The "all other" land cover class, which represented about 80 percent of the Basin area, could then be further divided into three classes: cropped area, area of permanent cover such as pasture, hay and perennial crops, and shrubs, for at total of six land covers. The six land covers are referred to as: "water" being waterbodies with surface area of at least 100 ha, "crop", "grass" being permanent cover, "shrub", "wetlands" and "bush."

7.2.4 1990s Land Cover Data Set

As previously mentioned, the current land cover condition was defined using classified satellite imagery developed for PFRA to deliver the Western Grains Transition Payment Program. The WGTPP scenes for the Basin were captured during the summer and fall seasons of 1994 and 1995. These original Landsat TM (bands 3,4,5) composites were geo-referenced to the 1:50,000 NTS road network and classified using supervised and unsupervised techniques.

The original use of the data was to validate producer claims under WGTPP. Part of this verification process included the cross tabulation of remotely sensed data (by quarter section) with other available sources of land use information (i.e., crop insurance, tax assessment, air photos, etc.). This process served an important business function for the program, but also provided a mechanism to identify and later correct gross errors in the remotely sensed data. The cross tabulation combined with original training and validation sites ensured that the classified product is a valid representation of 1994-95 land cover condition.

For the SLURP model the 11 classes of WGTPP were thematically generalized into 6 cover classes as depicted in Figure 7.2. The rationale for this generalization was to reduce the database into hydrologically significant cover types, effectively reducing the complexity of the SLURP model, and potentially streamlining the calibration process.

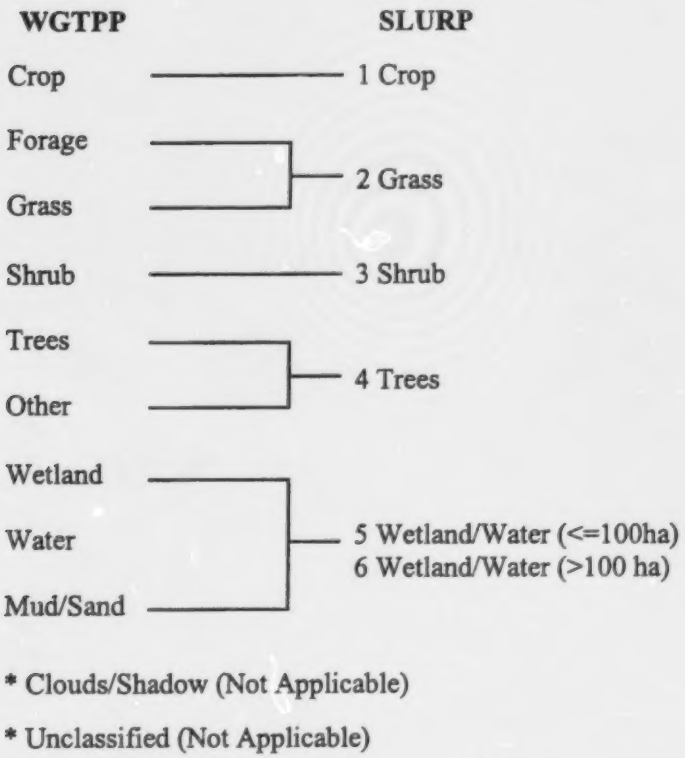
In order to accomplish this a number of assumptions were formulated. From a hydrologic standpoint, it was assumed that forage cover would have similar runoff characteristics and snow trapping potential as grassland. Therefore, "grass" and "forage" cover classes were combined into the larger "grass" cover type for the SLURP model.

The "other lands" classification (urban features, farm yards) presented a slightly different thematic challenge. Although representing a very small spatial extent (1.07% of the entire basin), in open terrain these features represent considerable snow trapping ability. It was assumed that yard sites would have similar snow trapping abilities as small stands of trees. Therefore, other lands were rolled into the "tree" class for purpose of the model.

Inspection of the "Mud/Sand" class in the WGTPP data showed that the occurrence of this cover type mainly occupied moist areas surrounding the water's edge. It was assumed that exposed mud detected by the WGTPP imagery was part of larger wetland complexes. Therefore "Mud/Sand" pixels were aggregated into the larger group of "Wetland/Water".

Other aggregation decisions were made on the basis of how SLURP handled land covers. The "Wetland" vegetation class and "Water" class were aggregated into the "Wetland/Water" classification for SLURP. In this instance, contiguous areas of wetland vegetation and open water were grouped into discrete complexes and then reclassified based on wetland area. The evaporation routines in SLURP allowed basins larger than 100 hectares to be handled differently than wetlands below this threshold.

Figure 7.2
Thematic Generalization of WGTPP Data for SLURP



7.2.5 Historic Land Cover Data

The initial pilot study by Trigon Mapping Resources made it clear that the cost associated with compiling historical land use from air photos was prohibitive (Trigon and SRC, 1997). The Edition 1 NTS maps were perceived to be a cost-effective source of standardized data that would be an acceptable alternative to photography. A contractor was hired to extract four data themes from historical NTS (circa 1960) mapsheets for use in the SLURP model: trees (polygons), waterbodies (polygons), marsh (polygons), and water courses (arcs). In accordance with specifications in the contract (see GIS and Technical Standards Committee Report) historical data were provided as Arc/Info coverages structured by layer and original extent. Original processing included eliminating "donut" polygons in each layer, joining sections into a seamless coverage and later merging all polygon layers into a single historical land use product.

With the completion of pre-processing and structural integrity testing (slivers, attribute definitions, etc.), work on historical data moved toward validating thematic content. Initial inspection consisted of visually checking for consistency between mapsheets and thematic accuracy of features against historical photography. These checks revealed a number of inconsistencies with the thematic content of the NTS data. Table 7.2 provides a brief summary of the errors detected.

Table 7.2 - NTS Detected Errors

Map Edge Error "Inter-Sheet"	Feature Identification Error "Intra-Sheet"
• Feature ending at neatline. • Different waterbody densities between mapsheets in similar terrain. • Different thematic definitions between mapsheets (i.e., marsh vs. water classification of the same wetland complex). • Different minimum mapping tolerances between mapsheets (water).	• Features below minimum mapping tolerance identified by NTS criteria. • Omission of features well above minimum mapping tolerance identified by NTS criteria. • Features delineated in the Edition 1 NTS maps but absent from late 1950s photography. • Generalization of multiple features into single unit. • Inconsistent use of generalization criteria. • Variable thematic definition of water body and marsh classes within a single mapsheet. • Variable enforcement of minimum mapping tolerances within a single mapsheet.

These types of errors are common with cartographic representations of the landscape. However, the magnitude and variability of error captured in the data were much greater than expected and begged the question, "Can we validly compare NTS data with contemporary land use inventories developed from space-borne imagery?"

The first test was to look for anamalous trends at a broad scale. The summary unit chosen was the ASA. The 11 classes of WGTPP data were thematically generalized to match the three areal features represented by the NTS. Area statistics were then generated for each ASA and results

for both time periods were compared. All but five ASAs exhibited the expected areal decreases of both tree and water classes between the Edition 1 NTS maps and WGTPP data. However, the five northern ASAs (mostly forested) exhibited a significant increase in water area. Upon more detailed inspection, these differences could be accounted for by the tendency of NTS data to generalize wetland areas surrounded by tree cover (i.e., large tree polygons containing many wetland areas greater that the minimum mapping tolerence). This generalization combined with the enhanced ability of TM data to consistently, and accurately, distinguish between wetland and tree cover collectively accounts for the differences between the two time periods in the forested ASAs.

The uncertainty encountered in the forested ASAs initiated a more detailed inquiry into the comparability of the two data sets. Narrowing the aggregation extent to a one square mile arbitrary grid, the two data sets were summarized and compared. It was found that over half of these grid samples had an increase in water acreage for the Edition 1 NTS maps. In many instances the increase was small (< 3%), however in some portions of the Basin the increase was significant (>20%), raising further concerns about the compatibility of the two data sets.

The final comparison was to directly overlay both datasets and identify feature differences. Realizing that a feature to feature match was highly improbable, it was postulated that the technique would isolate areas of the database with greatest error. For the water class, a high degree of uncertainty was revealed. As anticipated, there were numerous water and tree features existing in the NTS data but absent from WGTPP. However, a large number of tree and water features existing in current condition were absent from the historical data. Even more surprising is that the distribution of these occurrences appear to be somewhat random, not isolated to specific areas as one might expect. High levels of uncertainty make it difficult to determine which "loss scenarios" are real, and which are a function of data incomparability.

A number of observations have been made during the course of this investigation.

1. Edition 1 NTS maps have been derived from photography over a period of many years. In one instance, large features captured by the NTS did not exist in 1957 photography. Further investigation of historical records indicated the aerial photos were taken in 1949, constituting a nine year lag between the acquisition of base data and publication of the map. For this mapsheet a combination of 1949, 1957 and 1960 photography was used as a base. Thus, the spatial and thematic definition of features reflect the differences between years and seasons captured in the photography and do not provide a single "snap-shot" in time. Furthermore, the photography for this map was taken at different scales, introducing different levels of generalization from resolution of base data. Edition 1 NTS maps are manually interpreted cartographic products that provide a general overview of wetland and tree distributions across mapsheets. In a number of instances wetland features well above the minimum mapping tolerance are excluded from the NTS. This is problematic when attempting to identify wetlands impacted by agricultural practices when they are omitted erroneously from baseline data with great frequency.

2. Although rigid mapping criteria are set out for the compilation of the Edition 1 NTS maps. It is clear that application of these criteria varied both between and within mapsheets. This could be explained by considering that different interpreters may work on adjacent mapsheets or within a single mapsheet. Furthermore, the process must have often spanned over weeks to complete a single mapsheet, therefore it is understandable that the interpreters' application of a standard would be highly variable.

3. Based on the high level of uncertainty associated with the Edition 1 NTS maps, particularly wetland features, and the differences in feature definition between spectral and cartographic processes, it was concluded that the NTS maps could not be validly compared to the WGTPP data for change detection analysis or for SLURP modeling purposes. Furthermore, the large number of samples required to validly adjust the NTS data for comparison in SLURP made this approach impractical.

7.2.6 Land Cover Data Used in SLURP

Table 7.3 below presents the percent of each land cover type in each ASA for the 1990s as extracted from the WGTPP database.

Table 7.3 - 1990s Land Cover Areas (percent) by ASA

ASA	ASA Name	Water	Crop	Grass	Shrub	Wetland	Bush
4	WSR near Sheho	2	62	16	10	3	7
10	WSR to Theodore Reservoir	1	62	18	9	3	7
15	WSR to confluence with Yorkton Creek	0	55	23	11	4	7
20	Willow Brook	0	40	26	16	6	12
17	Cussed Creek	0	52	26	12	5	5
18	Yorkton Creek	1	70	17	4	4	4
6	Spirit Creek	0	88	1	6	1	4
8	Good Spirit Lake	8	42	27	8	4	11
11	WSR near Canora	1	72	15	2	6	4
1	Assiniboine R near Sturgis	1	41	11	9	7	31
5	Crooked Hill Creek near Canora	0	86	3	5	1	5
2	Assiniboine R at Kamsack	0	69	15	3	6	7
9	Little Boggy Creek	0	25	16	4	8	47
16	Stony Creek near Kamsack	0	86	0	0	9	5

ASA	ASA Name	Water	Crop	Grass	Shrub	Wetland	Bush
7	Shell River near Roblin	1	5	8	0	16	70
14	Shell River near Inglis	0	38	32	0	5	25
131	Local area east of Lake of the Prairies	0	58	23	5	3	11
132	Local area west of Lake of the Prairies	0	65	19	5	5	6
19	Conjuring Creek near Russell	0	54	23	0	5	18
22	Smith Creek	0	79	6	4	6	5
241	Local area east side above Russell	0	58	27	1	3	11
242	Local area west side above Russell	0	70	12	5	5	8
232	Local area west side above St. Lazare	0	63	19	6	3	9
231	Local area east side above St. Lazare	0	64	21	0	4	11

7.2.7 Digital Elevation Model

A Digital Elevation Model (DEM) was generated using 1:50,000 NTS hydrography and hypsography layers. The continuous raster surface was constructed using ARC/INFO's TOPOGRID. The process incorporated the NTS contours and spot elevations with hydrology features (break-lines) to produce the DEM. The DEM generated from this procedure is a "hydrologically correct" elevation surface, meaning that theoretical flow directions and flow paths can be derived from the DEM due to the incorporation of hydrologic features. These characteristics were required to generate the physiographic parameters for the SLURP model.

7.2.8 Generation of Physiographic Data

The SLURP model required a number of physiographic inputs as summarized in Table 7.4.

The calculations of linear and areal statistics are basic operations for contemporary GIS packages and were easily integrated into an automated Arc/Info GRID procedure that generated physiographic parameters for SLURP. However, the Distance parameters and Elevation Change parameters were much more involved. By incorporating a "hydrologically correct" elevation surface into the procedure, the theoretical flow directions and paths could be determined to provide a basis to calculate flow distances versus Euclidean (straight line) distance. Using the land cover data set, surfaces were generated that allocated flow distance to stream, flow distance

Table 7.4 - Physiographic Parameters Required for SLURP

Parameters	Units	* Land Cover	** ASA
ASA Number	N/A		X
ASA Name	N/A		X
ASA Area	km		X
Mean Latitude	degrees		X
Mean Elevation	m	X	
Land cover Percentage	N/A	X	
Channel Length	km		X
Mean Distance to Stream	km	X	
STDV Distances to Stream	km	X	
Mean distance downstream	km	X	
STDV of distances downstream	km	X	
Mean In Stream Distance	km	X	
Mean Elevation change to stream	m	X	
Mean Elevation change in stream	m	X	

* Parameter is calculated for each land cover class, within each ASA.
**Parameter is calculated for each ASA.

to basin outlet to each pixel in the land cover matrix. Consequently the process could easily establish the elevation of each land cover pixel and create surfaces that allocate elevation values from where the flow path intersected the stream and the basin outlet elevation. Simple boolean operations (i.e., In Stream Distance = Total Distance Down Stream – Distance to Stream) performed onthe surfaces calculated each physiographic parameter for each pixel. With these surfaces in place, regional functions were then used to average these parameters for each land cover class.

For the most part the above process worked well, however a number of topographic situations required custom programming. The most common occurrences were inconsistencies between manually generated basin definitions (ASA) and the auto-generated basins derived from the DEM. Although comparable in gently undulating terrain, incompatibility was most prevalent in complex or flat areas (humocky landscapes in the non-effective drainage area). The result was small pockets along the ASA edge that would not have flow distance measurements. Without flow distance values the other parameters could not be generated in these pockets This was overcome with a simple but effective method. Euclidian distances would be measured from the outer pixels in the flow distance grid and these flow distance pixels would be allocated to each cell in the dead area. Then the original flow distance would be added to the Euclidian to produce an estimate of flow distance to the basin outlet. All other parameters could then be generated once this was completed.

Similarly, large flat areas required a custom routine to calculate flow distance through large lakes or areas of very little relief.

7.2.9 Physiographic Data Used in SLURP

SLURP calculates the net radiation available in each ASA to melt snow based on recorded hours of bright sunshine, day-of-year, and the mean latitude of each ASA. Recorded temperature and precipitation are adjusted based on the elevation differences between the climate station at which they were recorded and the mean elevation of each ASA. The temperature lapse rate for all ASAs was assumed to be 0.75 degrees Celsius per 100 m elevation difference. The precipitation was assumed to increase 5 percent for each increase of 100 m for all ASAs. Table 7.5 lists the mean latitude and mean elevation of each ASA as determined by the DEM.

Table 7.5 - ASA Latitude and Elevation

ASA	ASA Name	Latitude (degrees north above equator)	Elevation (m above mean sea level)
4	WSR near Sheho	51.76	559
10	WSR to Theodore Reservoir	51.52	556
15	WSR to confluence with Yorkton Creek	51.42	550
20	Willow Brook	51.26	642
17	Cussed Creek	51.33	572
18	Yorkton Creek	51.10	535
6	Spirit Creek	51.79	543
8	Good Spirit Lake	51.61	504
11	WSR near Canora	51.39	502
1	Assiniboine R near Sturgis	52.10	575
5	Crooked Hill Creek near Canora	51.79	513
2	Assiniboine R at Kamsack	51.78	503
9	Little Boggy Creek	51.55	593
16	Stony Creek near Kamsack	51.31	522
7	Shell River near Roblin	51.62	660
14	Shell River near Inglis	51.16	577
131	Local area east of Lake of the Prairies	51.33	543

ASA	ASA Name	Latitude (degrees north above equator)	Elevation (m above mean sea level)
132	Local area west of Lake of the Prairies	51.33	502
19	Conjuring Creek near Russell	50.84	601
22	Smith Creek	50.96	525
241	Local area east side above Russell	50.90	539
242	Local area west side above Russell	50.95	506
232	Deerhorn Creek and local area west side above Assiniboine R near St. Lazare	50.72	499
231	local area east side above Assiniboine R near St. Lazare	50.95	539

An additional adjustment is made to temperatures and rainfall rates in SLURP from the mean elevation of each ASA to the mean elevation of each land cover within the ASA. These mean elevations are listed in Appendix I.

Physiographic data are also required by SLURP to route the daily overland flows generated by the vertical water balance "tanks" for each land cover to the outlet of the ASA. The data required for each land cover within each ASA to do this are:

- the mean of overland distances from each pixel of the land cover parcel to the nearest stream (km);
- the standard deviation of those overland flow distances (km);
- the mean change in elevation from each pixel of land cover to the point where overland flow from that pixel enters the nearest stream (m);
- the mean of in-stream flow distances from the point where the overland flow from each pixel enters the stream to the ASA outlet (km);
- the standard deviation of those in-stream flow distances (km); and
- the mean change in elevation from the point where the overland flow from each pixel enters the stream to the ASA outlet (m).

The values for these distances and elevations for each land cover within each ASA are tabulated in Appendix I.

7.2.10 Meteorologic Data

The SLURP model requires several types of meteorologic data. These data were provided by Environment Canada. Data covered the years 1953 through 1957, and 1991 through 1997,

although only September 1993 through 1997 was eventually used in the model. Data provided included:

- daily average temperature;
- daily precipitation;
- daily dewpoint temperature; and
- daily hours of bright sunshine.

Table 7.6 lists the 16 climate stations with daily precipitation in the 1990s used in the model. The station locations are overlaid on a map of the ASAs in Figure 7.3. Using GIS analysis, the weighting given to each station could be determined to find the daily precipitation for each ASA.

Table 7.6 - Climate Stations with Daily Precipitation

Station Name	Station Number
Bangor	4010400
Cote	4011846
Fenwood	4012483
Good Spirit Lake	4012943
Langenburg	4014145
Margo	4015020
Parkerview	4015870
Rocanville	4016842
Yorkton A	4019080
Pelly	4086000
Pelly 2	4086001
Binscarth	5010216
Boggy Creek	5010310
Rossburn 4 North	501KE01
Pine River	5042169
Swan River 2	5042805

Figure 7.3
Daily Precipitation

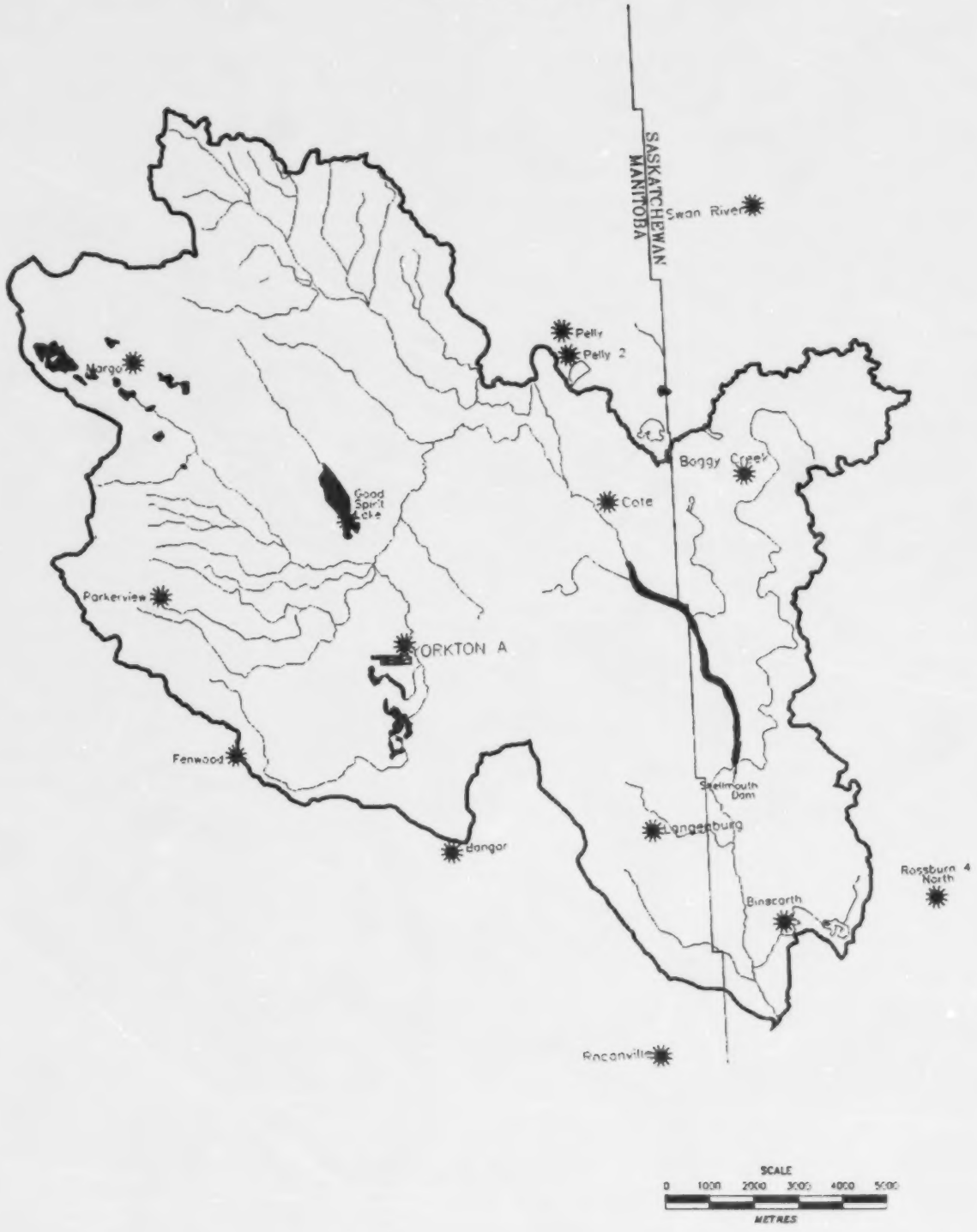


Table 7.7 lists the 14 climate stations with daily average temperature in the 1990s used in the model. The station locations are overlaid on a map of the Basin in Figure 7.4. Using GIS analysis, the weighting given to each station was determined to find the daily average temperature for each ASA.

Table 7.7 - Climate Stations with Daily Average Temperature

Station Name	Station Number
Atwater	4010310
Cote	4011846
Fenwood	4012483
Good Spirit Lake	4012943
Langenburg	4014145
Parkerview	4015870
Paswegin	4015960
Rocanville	4016842
Yorkton A	4019080
McKague 2	4085052
Pelly	4086000
Binscarth	5010216
Pine River	5042169
Swan River 2	5042805

Daily average dewpoint temperatures for the 1990s were available at Yorkton, Hudson Bay, and Dauphin. Daily hours of bright sunshine data was available and Yorkton, Hudson Bay and Wynyard. The station locations for these two parameters are overlaid on maps of the Basin in Figures 7.5 and 7.6. Using GIS analysis, the weighting given to each station was determined to find the daily average dewpoint temperatures and daily hours of bright sunshine for each ASA.

In addition, the upgraded SLURP routines for blowing snow and frozen soil infiltration required to following meteorologic data:

- hourly temperature;
- hourly dewpoint temperature; and
- hourly wind speed.

All the hourly data were taken from the Yorkton climate station and applied to the entire Basin.

Figure 7.4
Daily Temperature

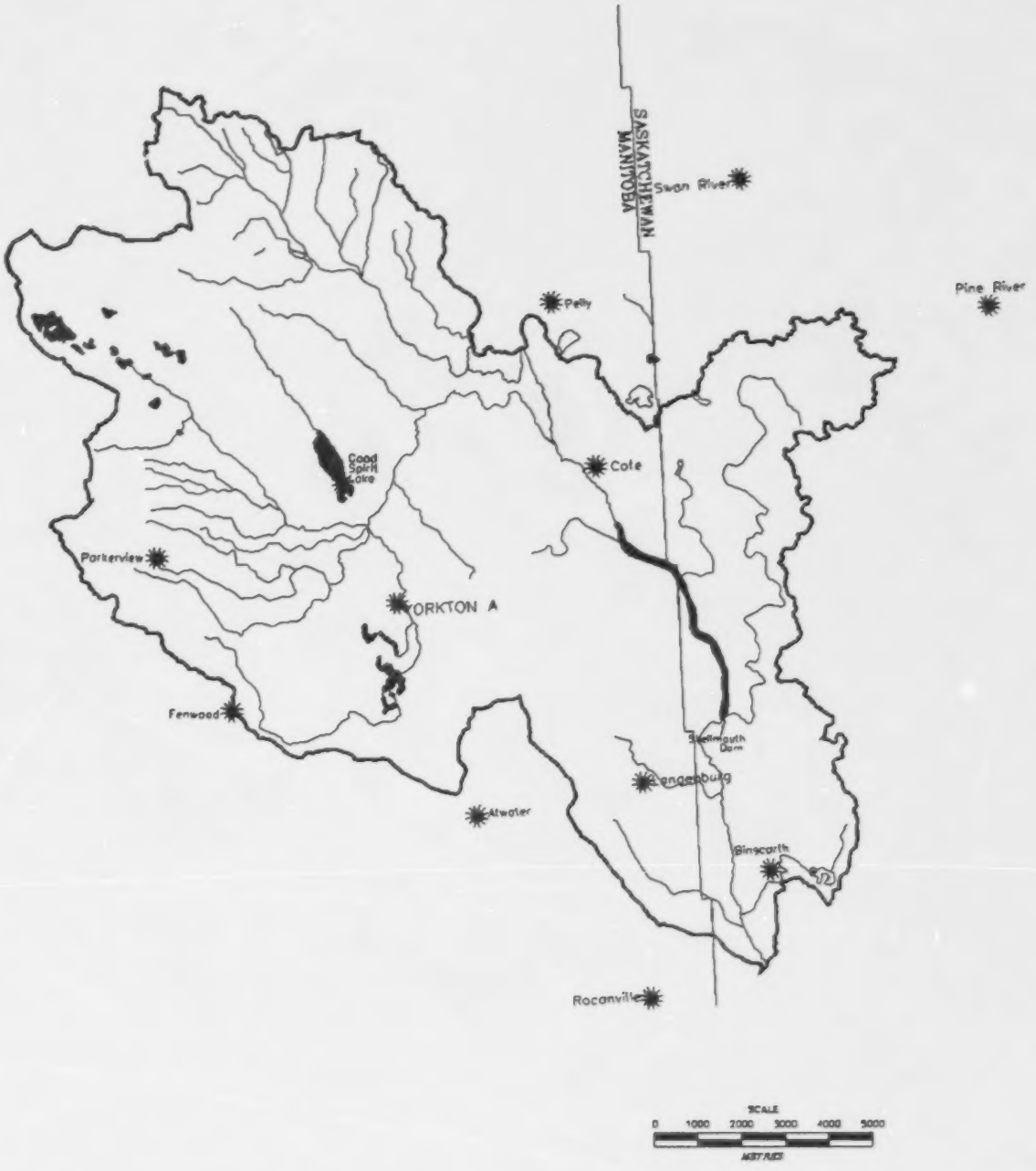


Figure 7.5
Daily Dew Point

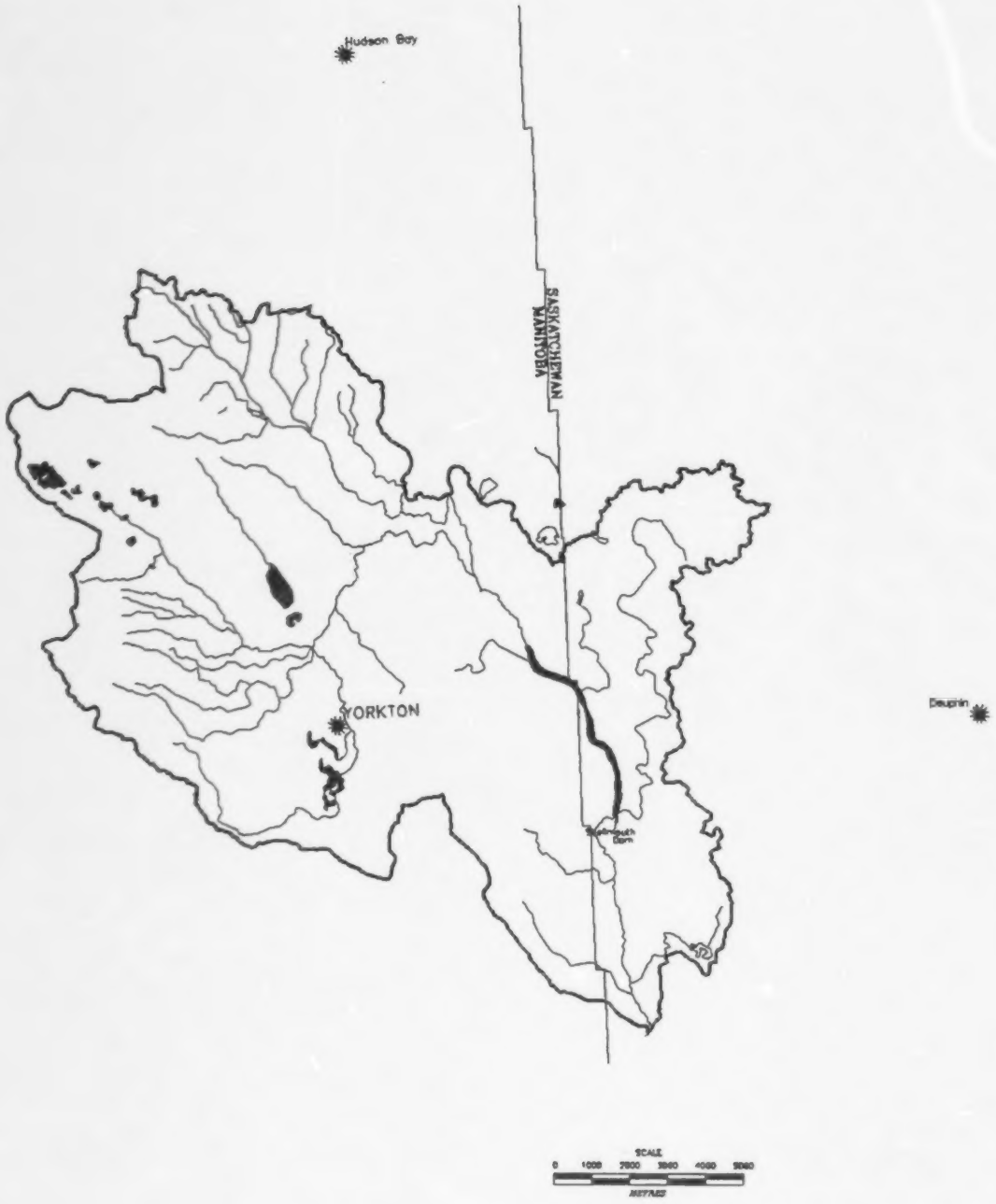
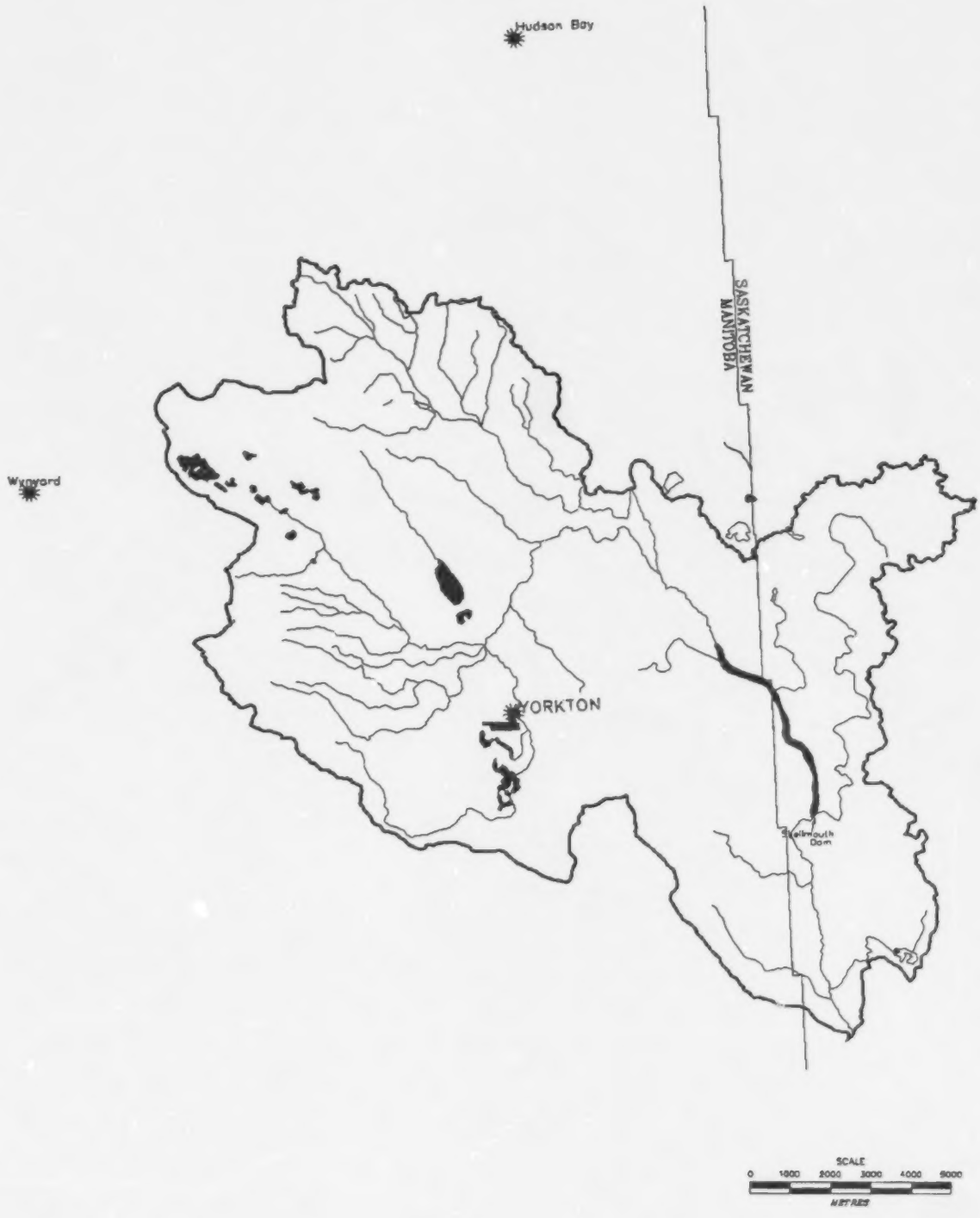


Figure 7.6
Daily Sunshine



7.2.11 Hydrologic Data

Recorded streamflow data are required in the model to calibrate various parameters and to verify the calibrations. Over the years, there have been 23 streamflow recording stations operated in the Basin, and five lake water level stations. The following table lists the stations, and indicates if they were in operation during the intended study periods of 1954-57 and 1993-97.

Table 7.8 - Hydrometric Stations in the Upper Assiniboine River Basin

Station Number	Station Name	1954-57	1993-97	Used as ASA
05MB001	Yorkton Creek near Ebenezer	Yes	Yes	Yes
05MB002	Whitesand River near Kamsack	No	No	No
05MB003	Whitesand River near Canora	Yes	Yes	Yes
05MB004	Whitesand River near Sheho	1957	No	Yes
05MB005	Willow Brook near Willowbrook	No	Yes	Yes
05MB006	Crooked Hill Creek near Canora	1956-57	1993,94,97	Yes
05MB007	Spirit Creek near Buchanan	1957	1993-95	Yes
05MB008	Whitesand River near Springside	No	1993-94	No
05MB011	Van Pattens Creek near Kuroki	No	No	No
05MB012	Lawrie Creek near Isinger	No	No	No
05MC001	Assiniboine River near Sturgis	Yes	Yes	Yes
05MC002	Stoney Creek near Stenen	1957	Yes	No
05MC003	Lilian River near Lady Lake	No	Yes	No
05MC004	Conjuring Creek near Preeceville	No	Yes	No
05MD002	Shell River near Duck Lake	No	No	No
05MD004	Assiniboine River near Kamsack	Yes	Yes	Yes
05MD005	Shell River near Inglis	Yes	Yes	Yes
05MD006	Little Boggy Creek near Cote	1957	No	Yes
05MD007	Shell River near Roblin	No	Yes	Yes
05MD010	Stoney Creek near Kamsack	No	Yes	Yes
05ME001	Assiniboine River near Russell	Yes	Yes	Yes
05ME005	Conjuring Creek near Russell	No	Yes	Yes

Station Number	Station Name	1954-57	1993-97	Used as ASA
05ME007	Smith Creek near Marchwell	No	Yes	Yes
05MB009	Theodore Reservoir near Theodore	No	Yes	Yes
05MB010	Good Spirit Lake near Canora	No	Yes	Yes
05MB013	Fishing Lake near Wadena	No	Yes	Yes
05MB014	York Lake near Yorkton	No	Yes	No
05MD009	Lake of the Prairies near Shellmouth	No	Yes	Yes

A set of daily flow data with the effect of Shellmouth Dam operations removed for the Assiniboine River at Shellmouth was developed by Manitoba Conservation using recorded reservoir levels and known outflows for use in the SLURP model.

Known operations of the Good Spirit Lake control structure and known volumes of discharge from Good Spirit Lake were used to construct an array of estimated daily flows from the lake.

7.3 Model Application

7.3.1 Physical Process Parameters

The SLURP model was applied by first setting parameters that reflect physical processes and can be determined or approximated from sources outside of the SLURP model. Examples of such parameters are the temperature and precipitation lapse rates presented earlier.

7.3.1.1 Land Cover Parameters

(1) Soil Heat Flux

Soil heat flux is the amount of solar energy being absorbed into the soil profile. The variation of daily soil heat flux through the year was approximated using a sine curve. The curve was defined by peak day of soil heat flux of August 1 and soil heat flux amplitude as 10 percent of net radiation for all land covers.

(2) Evapotranspiration

SLURP had three options for calculating evapotranspiration from land surfaces; Morton's Complementary Areal method, the Granger method, and the Spittlehouse/Black method. Each of these is described in the SLURP manual (Kite, 1997) which contains further research references. The Spittlehouse/Black method required more information than was available for application in the Basin. The Granger method was selected after initial trials using both the Morton and Granger methods. The Granger routine converts the daily sunshine hours data into net radiation and also uses the daily temperature and dewpoint data to determine the vapour pressure gradient.

Required parameters include the ground surface albedo, maximum and minimum snow albedos, all for the calculation of the net radiation, and a Granger wind speed function parameter. This last parameter reflects aerodynamic surface roughness. The values for these four parameters used in the model are listed below for the four dryland surface covers.

Table 7.9 - Granger Evapotranspiration Parameters

Land Cover	Ground Surface Albedo	Maximum Snow Albedo	Minimum Snow Albedo	Granger Wind Speed Function Parameter
Crop	0.2	0.8	0.4	50
Grass	0.18	0.8	0.4	60
Shrub	0.16	0.8	0.4	70
Bush	0.14	0.8	0.4	80

Evaporation from waterbodies had one option in SLURP; use of the Morton Complementary Lake Evaporation model. A significant modification to SLURP-PBS was made in consultation with Dr. R. J. Granger during the course of calibration to add a second option which would use the Priestly-Taylor (P-T) Evapotranspiration formula. This option was used for both the wetlands land cover class and the lakes land cover class. Input parameters were a maximum snow albedo of 0.80, a minimum snow albedo of 0.40, water albedo of 0.30, and wetland albedo of 0.25. The P-T formula requires an empirical constant which relates actual to equilibrium evaporation. For saturated surfaces such as the epen water lakes and the wetlands covers used in this application of SLURP, a value of 1.26 applies (Marsh and Bigras, 1988). This value was hard-coded into the SLURP-PBS for this option.

(3) Canopy Interception

Any precipitation is first intercepted by the canopy. The daily maximum allowable interception depends on the Leaf Area Index (LAI) which in SLURP is varied parabolically though the year from a minimum on January 1 to a maximum on July 1 and back to the January 1 minimum. Two coefficients *a* and *b* relate the daily maximum interception rate to the daily maximum LAI in the formula:

$$\text{Interception} = a\,(\text{LAI}_{\text{Max}})(\text{Precipitation}^{b})$$

Daily precipitation in excess of the interception proceeds to the snow storage tank in winter, or else to the fast store tank. Intercepted precipitation accumulates in the canopy storage until the canopy capacity is reached. However, the canopy storage is depleted by daily evaporation. Any precipitation in excess of the canopy capacity proceeds to either the snow store or fast store. The following table lists the canopy parameters applied in the Basin.

Table 7.10 - Canopy Parameters

Land Cover	Jan 1 LAI	Jul 1 LAI	*a*	*b*	Canopy Capacity (mm)
Water	1	1	0	1	5
Crop	0.1	1	0.75	1	10
Grass	0.5	1	0.75	1	20
Shrub	0.25	1	0.75	1	40
Wetland	1	1	1	1	100
Bush	0.2	1	0.75	1	40

For the "water" cover, the coefficient *a* was set to zero so that no interception occurs at all. The other parameters for the water cover are irrelevant. The July 1 LAI for all land covers was set to unity to simplify the remaining parameters. The January 1 LAI for Crop, Grass, Shrub and Bush were set relative to each other and to the maximum of 1.0 on July 1. The exponent *b* was set to unity, again to simplify setting the parameters, while the coefficient *a* was set to 0.75 for Crop, Grass, Shrub, and Bush to represent an interception rate of 75 percent of the daily maximum rate based on the LAI. The canopy capacities given above for Crop, Grass, Shrub and Bush represent increasing capacity based on the density of aboveground material such as stems, leaves, and branches.

For the wetland land cover, the parameters were set so that all precipitation is intercepted up until the capacity of 100 mm is exceeded. This was done to maximize the retention of the precipitation on the wetlands and exposing that retained precipitation to evaporation prior to any excess entering the stream flow system. This approach to using the canopy store in SLURP was developed during the calibration phase as an attempt to best mimic the wetland function of retaining precipitation in the watershed. The capacity value of 100 mm was determined during the calibration phase as large enough to prevent wetland contributions to simulated streamflow in 1994 while small enough to allow contribution to streamflow in 1995.

(4) Rain/Snow Division Temperature

The rain/snow division temperature determines at what daily average temperature the precipitation falls as either rain or snow, and at what temperature the snow begins to melt. It can be set for each land cover. This parameter was initially set to 0.0 degrees but was adjusted during calibration to modify the onset of snowmelt runoff from the various land covers. By adjusting this parameter, runoff was slightly delayed from the shrub and bush covers and advanced from crop and grass. The following table lists the Rain/Snow Division Temperature for each land cover.

Table 7.11 - Rain/Snow Division Temperatures

Land Cover	Rain/Snow Division Temperature (Celsius)
Water	0.2
Crop	-0.5
Grass	-0.4
Shrub	0.1
Wetland	0.3
Bush	0.5

(5) Snowmelt Calculation Parameters

SLURP has two routines for calculating daily snowmelt. The first is a simple degree day method based on the daily average temperature above the rain/snow division temperature. The second method is similar but also accounts for the daily net radiation. This second method is referred to as the "restricted degree-day" method and was the approach selected for use in the Basin on the basis of experience in Saskatchewan that temperature alone does not account entirely for snowmelt. Radiation does have an influence and this was apparent in better snowmelt simulation after initial trial runs with both options for the snowmelt routine. The following table gives the snowmelt parameters, *rate* and *a*, used in the formula:

$$\text{Snowmelt} = rate(\text{T-snow/rain T}) + a(\text{net radiation})$$

Table 7.12 - Snowmelt Parameters

Land Cover	*rate*	*a*
Water	0.75	0.01
Crop	0.9	0.01
Grass	0.85	0.01
Shrub	0.75	0.01
Wetland	0.75	0.01
Bush	0.7	0.01

(6) Flow Routing to ASA Outlet

SLURP first routes surface runoff from each land cover overland using the mean and standard deviations of the to-stream distances and the mean change in to-stream elevation presented

earlier, and an overland roughness factor to calculate hydraulic travel times from each land cover within an ASA to the stream network within that ASA. The model then uses the mean and standard deviations of the in-stream distances and the mean change in in-stream elevation presented earlier to compute in-stream travel times for each land cover within the ASA. In this approach there is no attenuation of the simulated runoff hydrograph from each land cover to the ASA outlet, there is only a lag effect. The following table lists the overland roughness parameter used for each land cover selected after a number of trial runs of the model.

Table 7.13 - Overland Roughness Parameters

Land Cover	Roughness Parameter
Water	4
Crop	5
Grass	5
Shrub	7
Wetland	5
Bush	8

(7) Initial Contents of Land Cover "Storage Tanks"

In SLURP, the initial contents of the Canopy and Fast Store "tanks" are set to zero. For this application of SLURP, the simulations were started on September 1, 1993. Therefore, the initial content of the snow storage tank was also set to zero for all six land covers. The initial contents of the Slow Store tank were set to 1 percent of slow store capacity for each land cover as 1993 was an extremely dry year and also because the slow store contents tended to accumulate over the course of the four-year simulation period.

(8) Precipitation Factor

The SLURP model allows for precipitation to be adjusted from the recorded amounts by factors entered for each land cover. This option was not used in the application to the Basin. The precipitation factor for each land cover was 1.00.

(9) Blowing Snow Parameters

As described in Pomeroy *et al.*, 1998, the blowing snow model requires five parameters in addition to those required by the original SLURP for each year and for each land cover class. However, in this application to the Basin, the parameters were held constant over the study period. The snow distribution parameter indicates to which land covers the blowing snow is redistributed. The water, crop and wetland covers were assigned to receive no redistributed snow, while grass, shrub and bush covers received increasing proportions of the snow. Three

parameters describe the "catch" characteristics of the land cover; height, silhouette area, and stalk density. The height parameter is quite significant in that no snow can be transported out of a land cover until the depth of snow reaches the specified height for that cover. An average fetch length is entered for each land cover class to represent how open the landscape is, allowing the wind profile to develop and snow to be transported. A minimum fetch of 300 m is required for transport out of a land cover class. Fetches of 300 m or less were specified for water, wetland, and bush land covers. Based on GIS analysis, fetches of 900 m were specified for crop, grass, and shrub land covers. The following table lists the parameters used for the Basin.

Table 7.14 - Blowing Snow Parameters

Land Cover	Redistribution (percent)	Height (m)	Area (m^2)	Stalk Density ($\#/m^2$)	Fetch Length (m)
Water	0	0.01	0	320	200
Crop	0	0.05	0	320	900
Grass	20	0.25	0	320	900
Shrub	30	1	0	320	900
Wetland	0	0.9	0.01	320	300
Bush	50	2	0.04	320	300

(10) Frozen Soil Infiltration Parameters

As described in Pomeroy *et al.*, 1998, the frozen soil infiltration model requires two parameters in addition to those required by the original SLURP for each year and for each land cover class. One parameter is the fall soil moisture as a percent of the maximum pore water content. The second parameter is the infiltration class. This is specified as either Unlimited, Limited, or Restricted. The Unlimited condition suggests a porous or heavily cracked soil where infiltration is not limited by the soil moisture. In the Limited condition, infiltration is governed by the snow water equivalent and by the water content in the frozen top 30 cm of soil. In the Restricted condition, infiltration is impeded by an impermeable layer and is therefore negligible. The model automatically switches from the Unlimited (U) or Limited (L) condition to the Restricted condition when an early melt is subsequently re-frozen to form an ice layer within the snow or at the bottom of the snow cover. The following table lists the frozen soil parameters used in the application to the Basin. The parameters for 1997 were set the same as for 1996 as runoff conditions were roughly similar.

Table 7.15 - Frozen Soil Infiltration Parameters

Land Cover	Fall Soil Moisture (percent)				Infiltration Class			
	1994	1995	1996	1997	1994	1995	1996	1997
Water	5	10	5	5	U	U	U	U
Crop	5	2	1	1	U	L	U	U
Grass	5	10	1	1	U	U	L	L
Shrub	5	10	5	5	L	U	U	U
Wetland	5	10	5	5	U	U	U	U
Bush	5	10	5	5	L	U	U	U

(11) Fast Store Tank Parameters

The fast store tank is characterized by three parameters for each land cover; maximum infiltration rate, maximum capacity, and retention constant. The values used in the Basin application are listed in the following table.

Table 7.16 - Fast Store Tank Parameters

Land Cover	Maximum Infiltration Rate (mm/day)	Maximum Capacity (mm)	Retention Constant (days)
Water	80	170	230
Crop	77	250	70
Grass	77	400	150
Shrub	80	380	50
Wetland	80	50	170
Bush	80	440	75

(12) Slow Store Tank Parameters

The slow store tank is characterized by two parameters for each land cover; maximum capacity and retention constant. The values used in the Basin application are listed in the following table.

Table 7.17 - Slow Store Tank Parameters

Land Cover	Maximum Capacity (mm)	Retention Constant (days)
Water	370	140
Crop	4000	2000
Grass	7000	1300
Shrub	2000	3500
Wetland	370	140
Bush	7500	7300

A substantial modification was made to the Slow Store tank at the request of the Drainage and Flood Control Committee to better represent prairie runoff conditions. SLURP was written to direct percolation from the slow store tank to the outlet of the ASA. In prairie conditions, deep percolation often goes into deep aquifers which do not discharge at all, or do not discharge within the Basin, much less the ASA. Even if they do discharge within the Basin, it is often at a time scale much longer than the four-year period in this application. Therefore, SLURP was modified so that for each land cover within each ASA, the percolation from the slow store tank could be directed either to the ASA outlet, or to deep storage. The following table lists the selection made for each land cover within each ASA on the deep percolation option. In the table, the capitalized letters indicate that the selection was made during the calibration phase. Lower case letters represent selections made on the basis of similar adjacent ASAs that had been selected during calibration.

Table 7.18 - Selection for Groundwater Percolation to Deep Aquifers

ASA	Water	Crop	Grass	Shrub	Wetland	Bush
WSR near Sheho	Y	Y	Y	Y	Y	Y
WSR to Theodore Reservoir	Y	Y	Y	Y	Y	Y
WSR to confluence with Yorkton Creek	Y	Y	Y	Y	Y	Y
Willow Brook	Y	Y	Y	Y	Y	Y
Cussed Creek	Y	Y	Y	Y	Y	Y
Yorkton Creek	Y	Y	Y	Y	Y	Y
Spirit Creek	N	N	N	N	N	N
Good Spirit Lake	N	N	N	N	N	N
WSR near Canora	Y	Y	Y	Y	Y	Y

ASA	Water	Crop	Grass	Shrub	Wetland	Bush
Assiniboine R near Sturgis	N	N	N	N	N	N
Crooked Hill Creek near Canora	N	N	N	N	N	N
Assiniboine R at Kamsack	Y	Y	Y	Y	Y	Y
Little Boggy Creek	n	y	n	n	n	n
Stony Creek near Kamsack	n	n	n	n	n	n
Shell River near Roblin	N	Y	N	N	N	N
Shell River near Inglis	N	Y	N	N	N	N
Local area east of Lake of the Prairies	n	y	y	n	n	n
Local area west of Lake of the Prairies	n	n	n	n	n	n
Conjuring Creek near Russell	n	y	y	n	n	n
Smith Creek	n	n	n	n	n	n
Local area east side above Russell	n	y	y	n	n	n
Local area west side above Russell	n	n	n	n	n	n
Local area west side above St. Lazare	y	y	y	y	y	y
Local area east side above St. Lazare	n	y	y	n	n	n

Y, y = Yes, groundwater percolates to deep aquifers or is otherwise lost
N, n = No, deep groundwater percolation shows up at ASA outlet

7.3.1.2 Treatment of Controlled Lakes

Reservoirs, lakes, and major water control complexes can significantly modify the downstream streamflow hydrograph. To deal with these situations, SLURP allows the computed runoff hydrographs at an ASA outlet to be modified by an external program supplied by the user. This program can be written to modify the hydrograph computed by SLURP to reflect the storage and operation effects of a reservoir, lake or water control complex.

In the case of Theodore Reservoir, no major operations are carried out and the reservoir does not have any significant impact on the stream hydrograph during large flood events. Thus Theodore Reservoir was not simulated in the SLURP model.

Lake of the Prairies does have a major impact on the streamflow hydrograph, however, the decision of the Drainage and Flood Control Committee was to not simulate the operations of this reservoir in SLURP. As discussed above under the heading of Hydrometric Data, a set of daily flow data with the effect of Shellmouth Dam operations removed for the Assiniboine River at Shellmouth was developed by Manitoba Conservation using recorded reservoir levels and known outflows for calibration of the SLURP model.

To eliminate the need for developing external programs to route inflow hydrographs through Good Spirit Lake and the Yorkton South Complex, the SLURP was modified to simply replace the computed hydrograph at the respective ASA outlets with the recorded daily flows. In the case of Good Spirit Lake, daily outflows over the period of simulation were estimated based on records of operation of the control structure, known volumes of water released, and on measured and estimated downstream flows.

7.3.1.3 Parameters for Routing Between ASAs

SLURP provides for two alternatives methods of routing the computed hydrograph at the outlet of one ASA to the outlet of the next downstream ASA. The simpler method is referred to as hydrologic storage routing, and requires the input of only two routing parameters. The second is a hydraulic routing method called Muskingum-Cunge, which requires the input of the channel length, change in channel elevation, channel roughness, average width, and average depth. The simpler storage routing method was selected after initial trials using the Muskingum-Cunge method. The two parameters for the storage routing method are a coefficient "alpha", and an exponent "beta". The following table lists these two parameters for each stream reach.

Table 7.19 - ASA Routing Parameters

Upstream ASA	Downstream ASA	alpha	beta
Sheho	Theodore Res	50	1
Theodore Res	Springside	50	1
Springside	Canora	50	1
Willow Brook	Yorkton Cr	10	0.5
Cussed Cr	Canora	50	1
Yorkton Cr	Canora	50	1
Spirit Cr	Good Spirit Lake	10	0.05
Good Spirit Lake	Canora	50	1
Canora	Kamsack	50	1
Sturgis	Kamsack	50	1
Crooked Hill Cr	Kamsack	50	1
Kamsack	Lake of Prairies West	10	0.5
Little Boggy Cr	Lake of Prairies East	10	0.5
Stony Cr	Lake of Prairies West	10	0.5
Roblin	Inglis	10	0.5

Upstream ASA	Downstream ASA	alpha	beta
Inglis	Lake of Prairies East	50	1
Lake of Prairies East	Lake of Prairies West	10	0.5
Lake of Prairies West	Russell West	10	0.5
Conjuring Cr	Russell East	10	0.5
Smith Cr	Russell West	10	0.5
Russell East	Russell West	10	0.5
Russell West	St. Lazare	10	0.5
Deerhorn Cr	St. Lazare	10	0.5

7.3.2 Calibration and Verification Process

The calibration process began with entering initial values for the parameters to be calibrated. The SLURP model has the capability of optimizing a limited number of the calibration parameters. It was found that better optimizations could be obtained by manually adjusting the entire range of parameters rather than allowing the optimization routine to work on a suite of eight or nine parameters for each land cover.

Initial results were poor when attempting to calibrate to all the hydrometric stations for 1994, 1995, and 1996. To improve the model performance, calibration efforts were focused on 1995 and 1996; the higher flow years. Secondly, on the advice of NWRI staff, efforts were further focused on only four hydrometric stations; Whitesand River near Canora, Assiniboine River near Sturgis, Shell River near Inglis, and Assiniboine River at Kamsack.

Model performance was measured by annual volume, spring peak flow magnitude, timing of spring peak flow, and r-squared. The r-squared values were computed for each station and each year using the differences between the daily recorded and daily simulated flows over the entire calendar year. Simulated hydrographs were also examined visually for goodness of fit to the recorded daily flows, with more emphasis placed on obtaining a good fit during the spring runoff period than at other times during the year.

Once satisfactory results were obtained over the calibration period, 1997 was included to verify the model performance.

7.3.3 Calibration and Verification Results

As stated above, model performance was measured by annual volume, spring peak flow magnitude, timing of spring peak flow, and r-squared at four major flow stations. The model parameters were adjusted over numerous trial runs to obtain the best possible performance for 1995 and 1996. The model was then run for 1997 as a verification. In all trials the model runs

were started September 1, 1993 to allow four months of "warm-up" prior to 1994, and 16 months of "warm-up" into 1995. The measurable results are tabulated in Tables 7.20 to 7.22 below. Annual hydrographs for each of the four stations for 1995, 1996 and 1997 are shown in Figures 7.7 through 7.18.

Table 7.20 - 1995 Calibration Results

Station	Average Annual Flow (m^3/s)		Spring Peak Flow (m^3/s)		Date of Spring Peak Flow		R-Squared
	Recorded	Simulated	Recorded	Simulated	Recorded	Simulated	
Sturgis	6.94	5.29	111	84.1	Apr 24	May 3	0.45
Canora	13.3	16.1	247	249	Apr 23	May 3	0.45
Kamsack	28.3	32.4	484	526	Apr 24	May 3	0.49
Shell R	6.81	6.81	65	85.1	Apr 24	May 10	0.46

Table 7.21 - 1996 Calibration Results

Station	Average Annual Flow (m^3/s)		Spring Peak Flow (m^3/s)		Date of Spring Peak Flow		R-Squared
	Recorded	Simulated	Recorded	Simulated	Recorded	Simulated	
Sturgis	3.36	4.66	35.4	24.3	Apr 26	Apr 20	0.58
Canora	3.74	3.61	59	27.8	Apr 18	May 3	0.65
Kamsack	11.4	13.6	124	92.1	Apr 25	Apr 25	0.78
Shell R	4.99	6.27	19.3	37.4	Apr 18	May 2	0.48

Table 7.22 - 1997 Verification Results

Station	Average Annual Flow (m^3/s)		Spring Peak Flow (m^3/s)		Date of Spring Peak Flow		R-Squared
	Recorded	Simulated	Recorded	Simulated	Recorded	Simulated	
Sturgis	2.51	5.47	78.1	48.4	Apr 22	Apr 29	0.58
Canora	4.42	4.87	96.1	95.2	Apr 22	Apr 21	0.61
Kamsack	11.6	16.4	263	162	Apr 25	Apr 21	0.7
Shell R	3.76	6.15	27.2	61.4	Apr 21	Apr 22	0.61

Figure 7.7
Assiniboine River near Sturgis - 1995

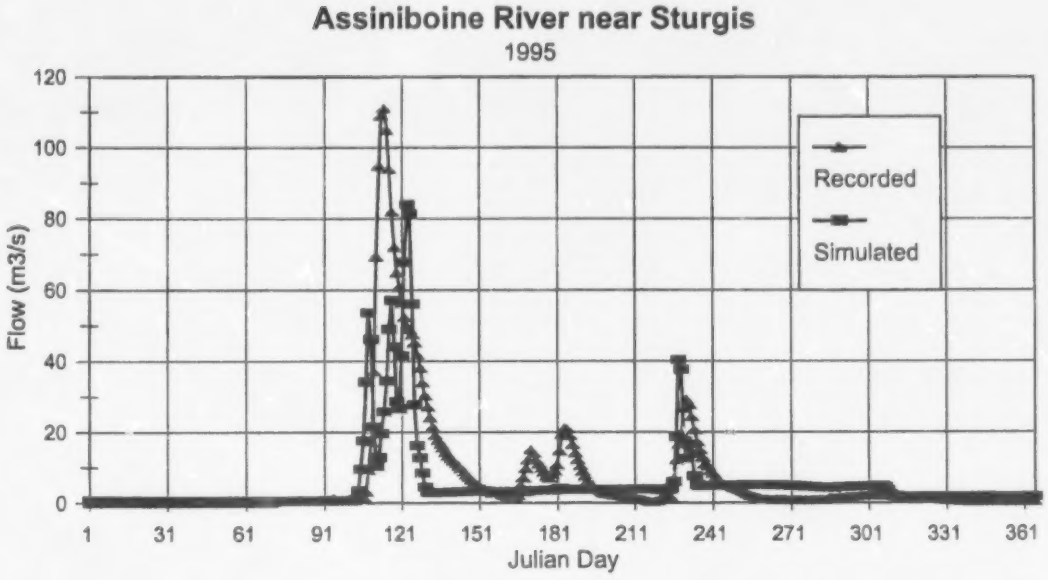


Figure 7.8
Whitesand River near Canora - 1995

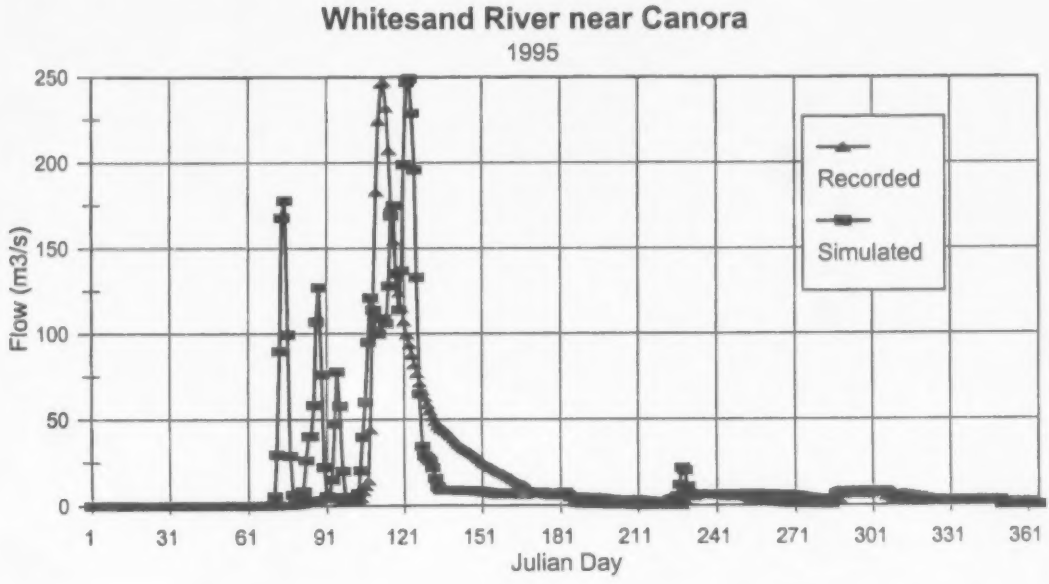


Figure 7.9
Assiniboine River at Kamsack - 1995

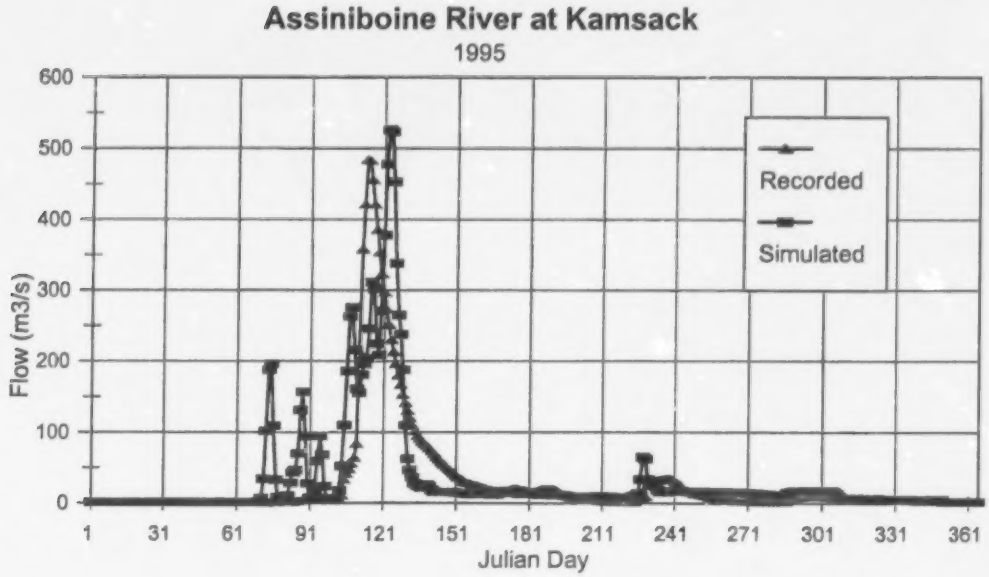


Figure 7.10
Shell River near Inglis - 1995

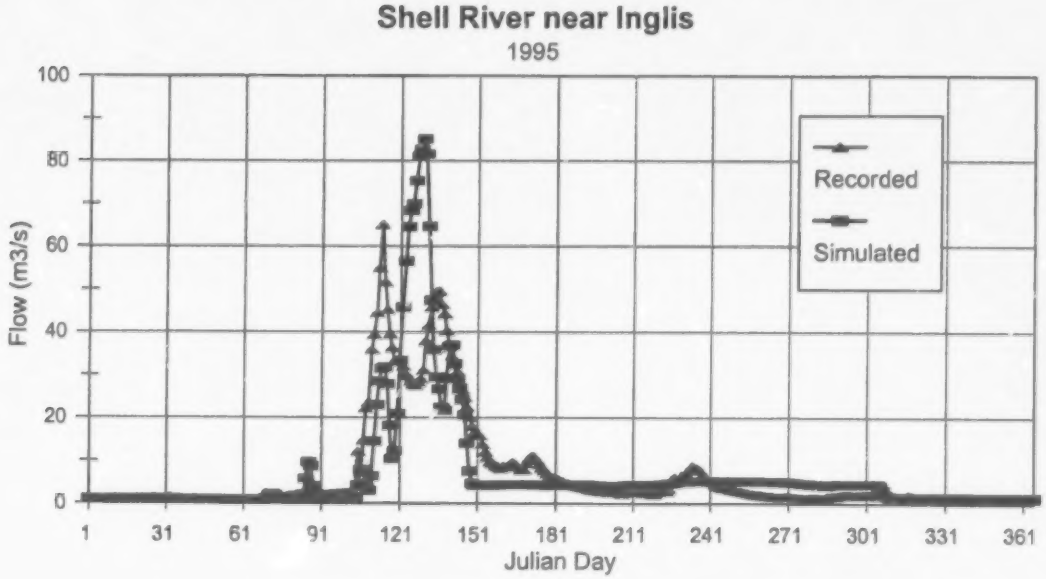


Figure 7.11
Assiniboine River near Sturgis - 1996

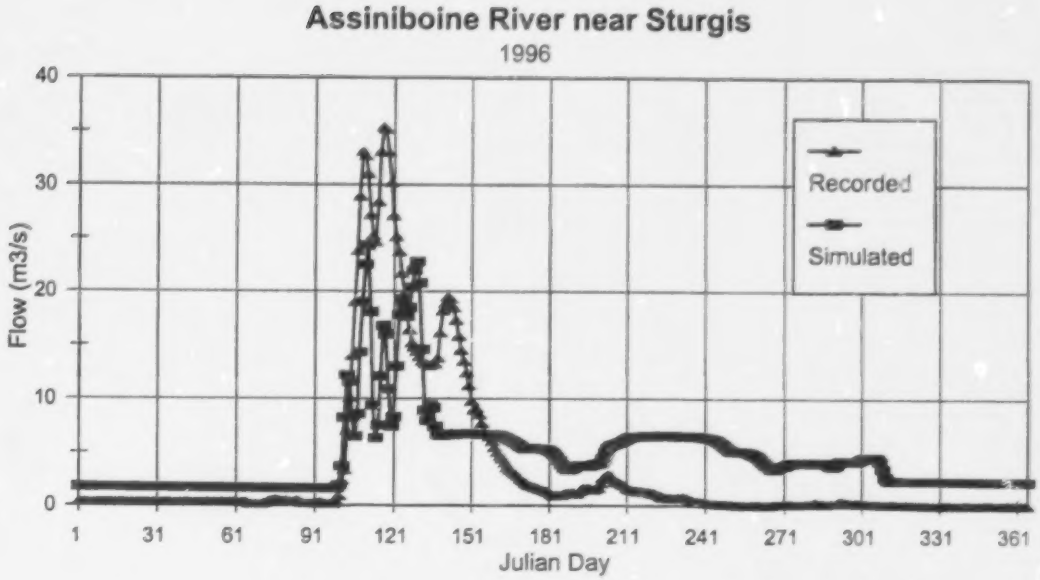


Figure 7.12
Whitesand River near Canora - 1996

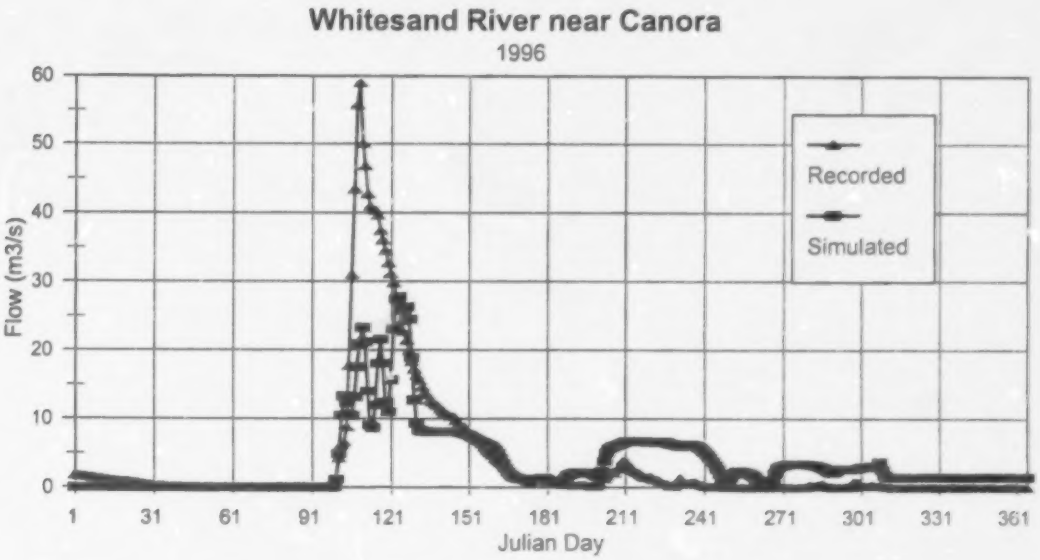


Figure 7.13
Assiniboine River at Kamsack - 1996

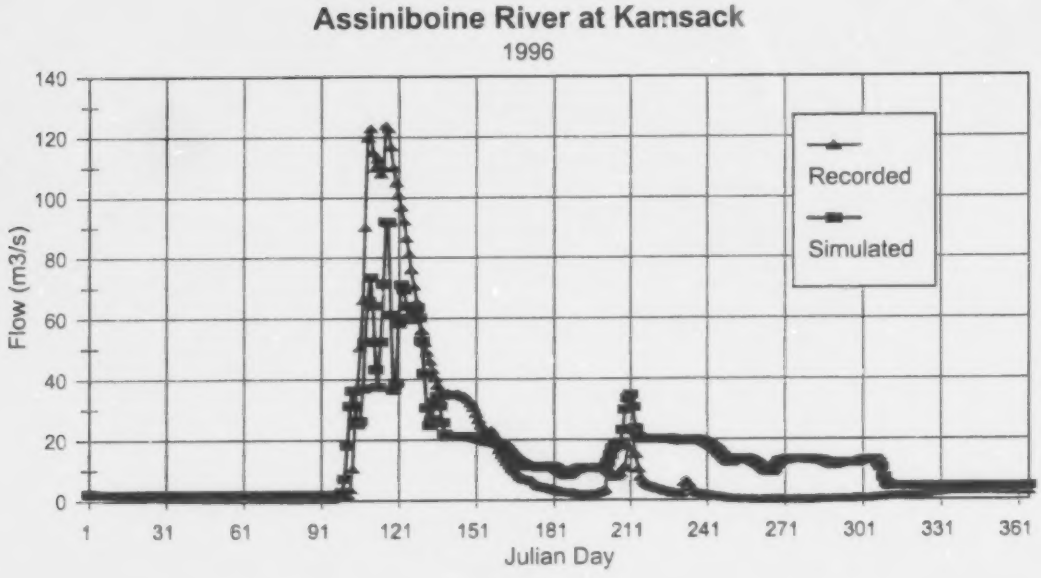


Figure 7.14
Shell River near Ingis - 1996

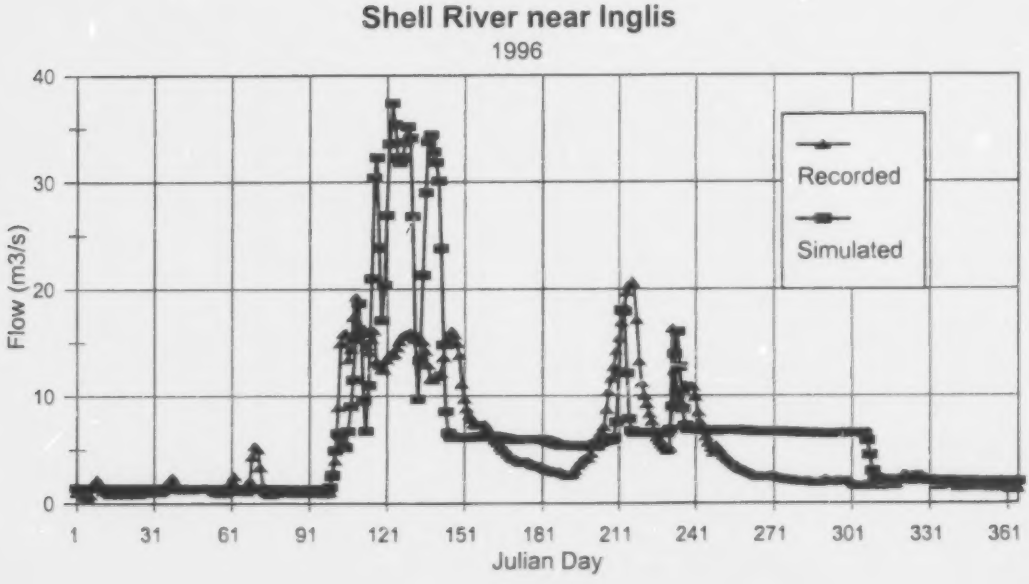


Figure 7.15
Assiniboine River near Sturgis - 1997

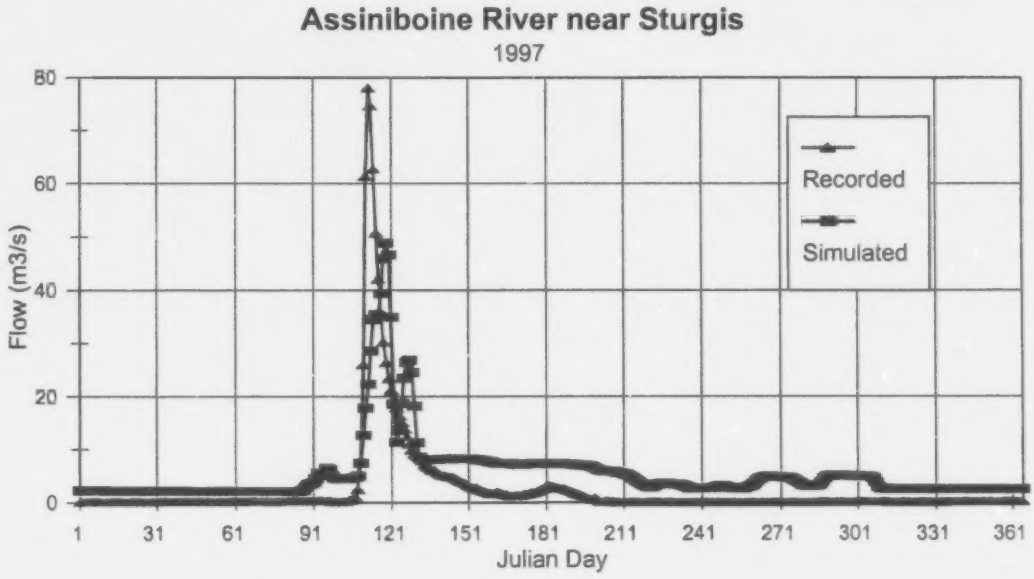


Figure 7.16
Whitesand River near Canora - 1997

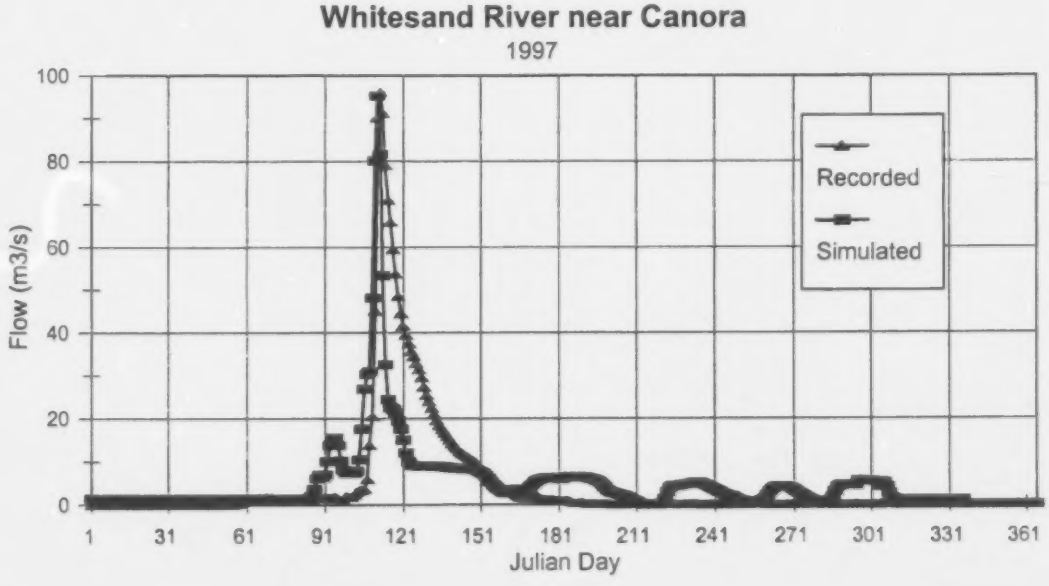


Figure 7.17
Assiniboine River at Kamsack - 1997

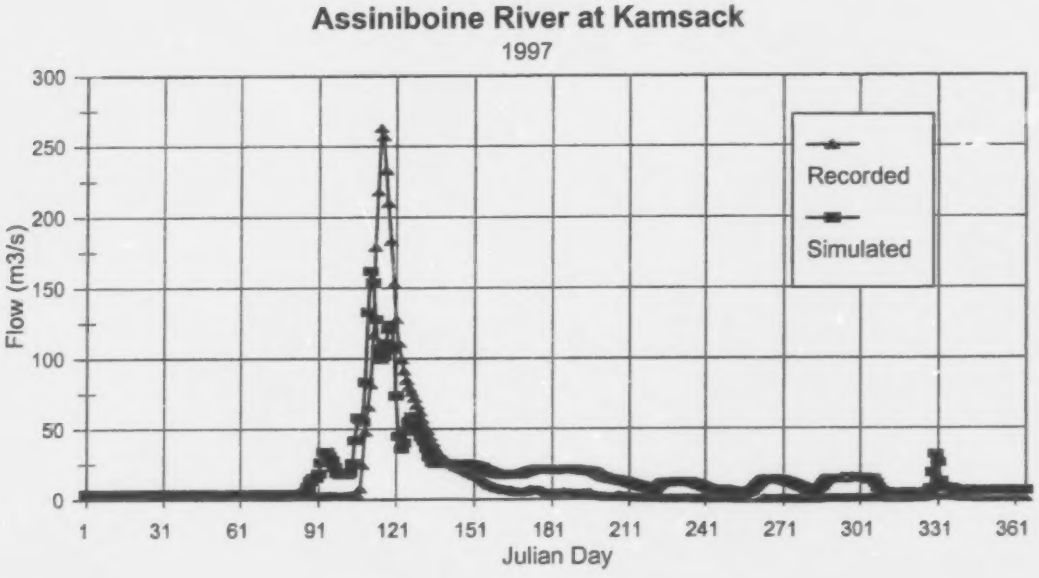
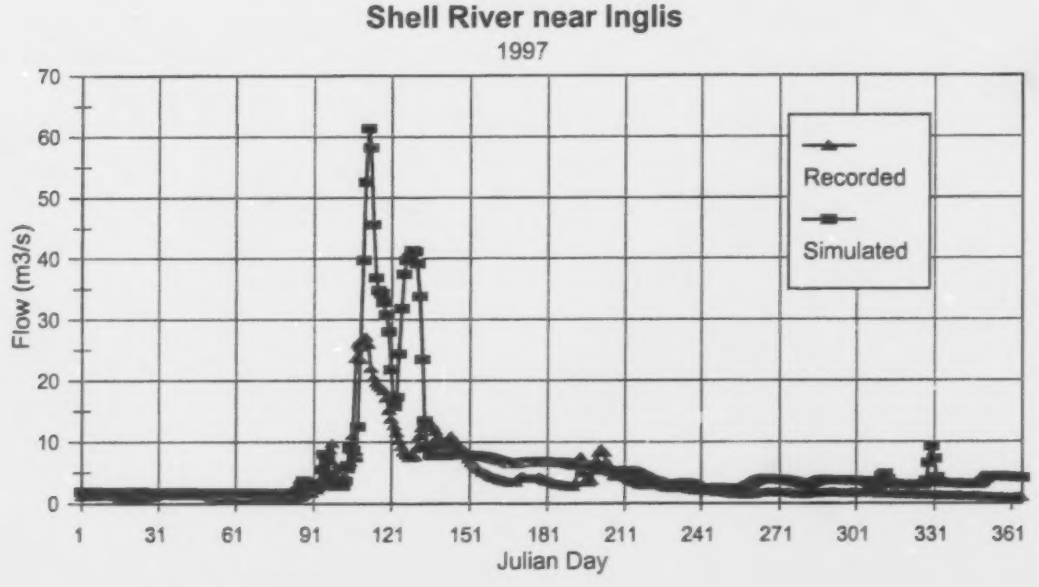


Figure 7.18
Shell River near Inglis - 1997



The above tables and the figures demonstrate that the model is reasonably well calibrated at these four stations for the years 1995, 1996, and 1997. Simulated annual volumes tend to be higher than recorded with 1997 showing this tendency the strongest. Simulated spring peak flows are reasonably close to recorded values at all four stations in 1995 and at Canora in 1996. The Shell River simulated peaks are consistently too high in all three years. The dates of spring peak flows are generally within 10 days of recorded values.

Visually, all four stations in all three years display at least two simulated "spikes" per spring runoff event whereas the recorded flows display a much smoother spring hydrograph. The most extreme case of the "spikes" is shown for the Whitesand River near Canora in 1995. These Canora spikes also show up in the Kamsack hydrograph downstream.

A second feature of the figures is that, except for Canora in 1996, the onset of snowmelt runoff tracks reasonably well with recorded flows. Also of significance is that the simulated spring recession is generally much steeper and ends at a lower flow rate than the recorded values. An incidental feature, not calibrated for, is the response to significant summer rainfall events in all three years at most stations. A final feature of note is that the simulations show a stronger and more constant base flow over the summer months whereas the recorded flows typically continue a gradual recession to lower flow values.

7.3.3.1 Model Results for 1994

As mentioned previously, the model did not perform well for 1994. The following table and Figures 7.19 through 7.22 demonstrate this poor performance. The annual volumes at three of the four stations are reasonably close. However, with the exception of the Shell River, the simulations show no peak flow response during the spring snowmelt period. This simulated response is largely due to the selection of the "unlimited" frozen soil infiltration parameter for both the Crop and Grass land covers. Trial runs with "limited" infiltration made for either of those two covers resulted in spring peak flows much greater than observed. The response of the Shell River in 1994 is due to the predominance of the bush cover in that watershed, which did have the "limited" infiltration.

The successively higher "humps" shown in each of the figures result from gradual filling of the fast store tanks with each precipitation event. As the tanks fill, the percolation out of the tanks increases and a portion of that outflow shows up as runoff.

Table 7.23 - 1994 Calibration Results

Station	Average Annual Flow (m^3/s)		Spring Peak Flow (m^3/s)		Date of Spring Peak Flow		R-Squared
	Recorded	Simulated	Recorded	Simulated	Recorded	Simulated	
Sturgis	1.27	1.16	12.1	1.46	Apr 16	Apr 14	0.027
Canora	1.93	1.44	9.83	2.3	Mar 26	Apr 4	0.21
Kamsack	4.41	3.81	22.5	4.98	Apr 13	Apr 13	0.081
Shell R	4.46	1.93	12.3	22	Apr 23	Apr 14	0.20

Figure 7.19
Assiniboine River near Sturgis - 1994

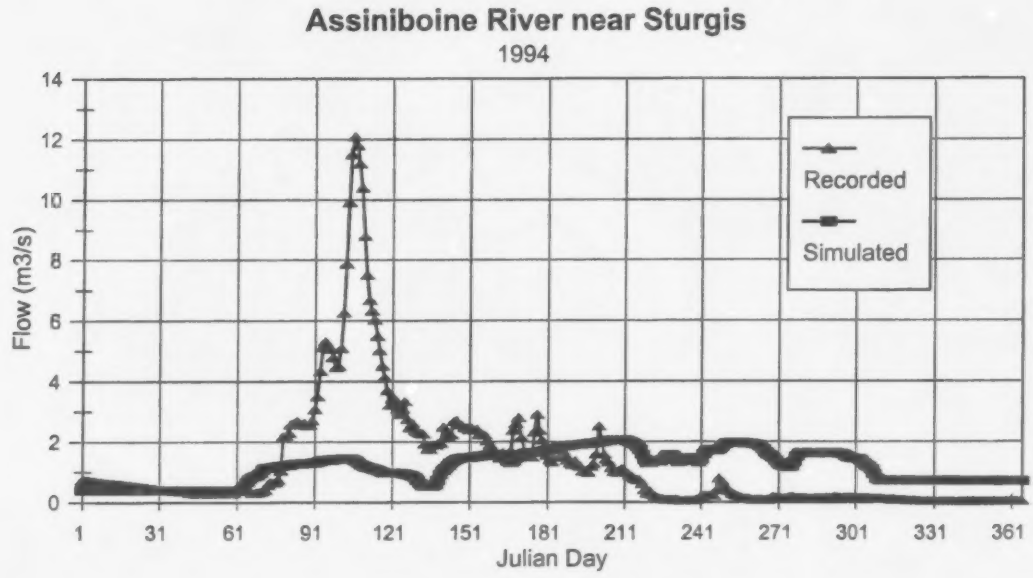


Figure 7.20
Whitesand River near Canora - 1994

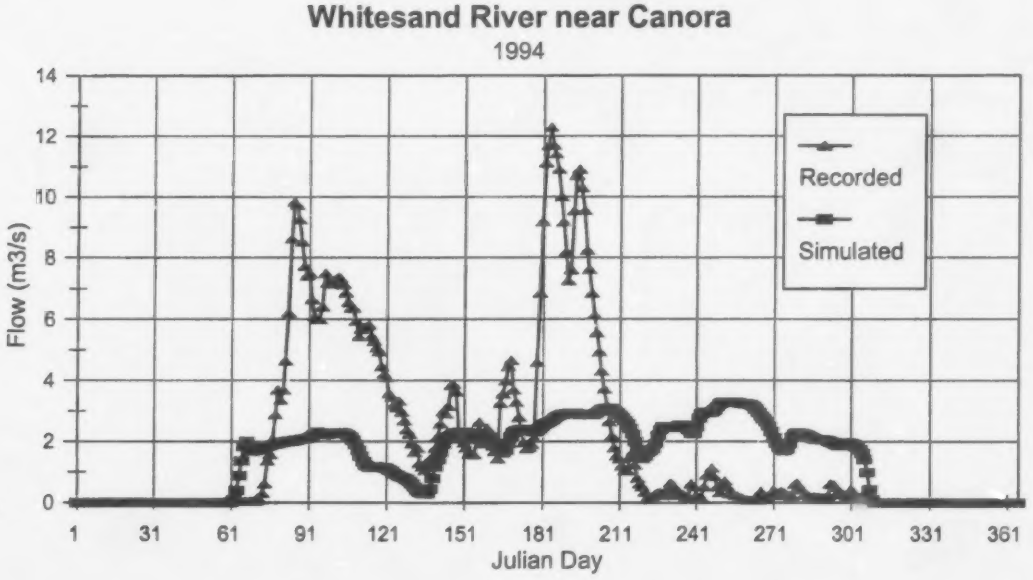


Figure 7.21
Assiniboine River near Kamsack - 1994

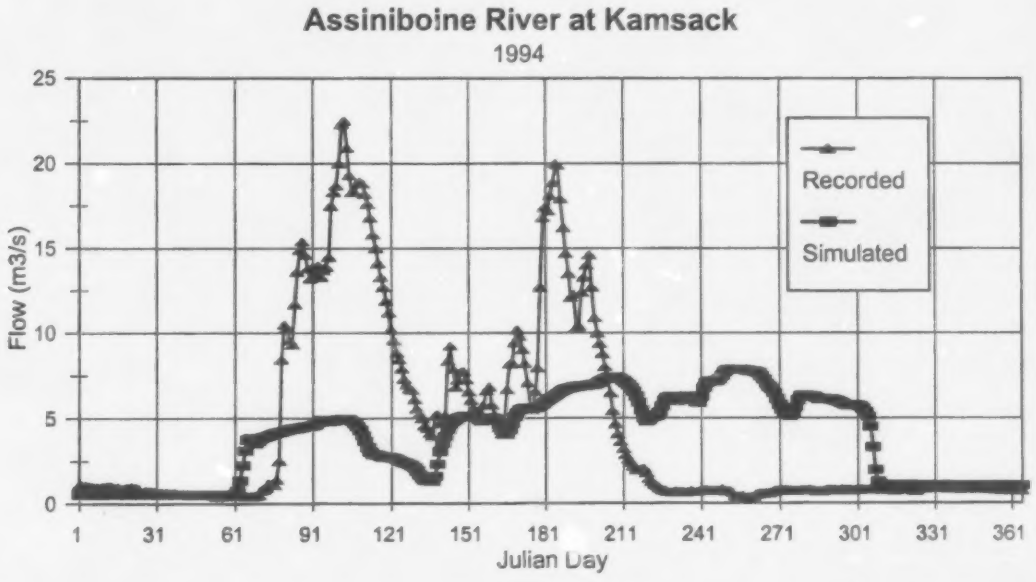
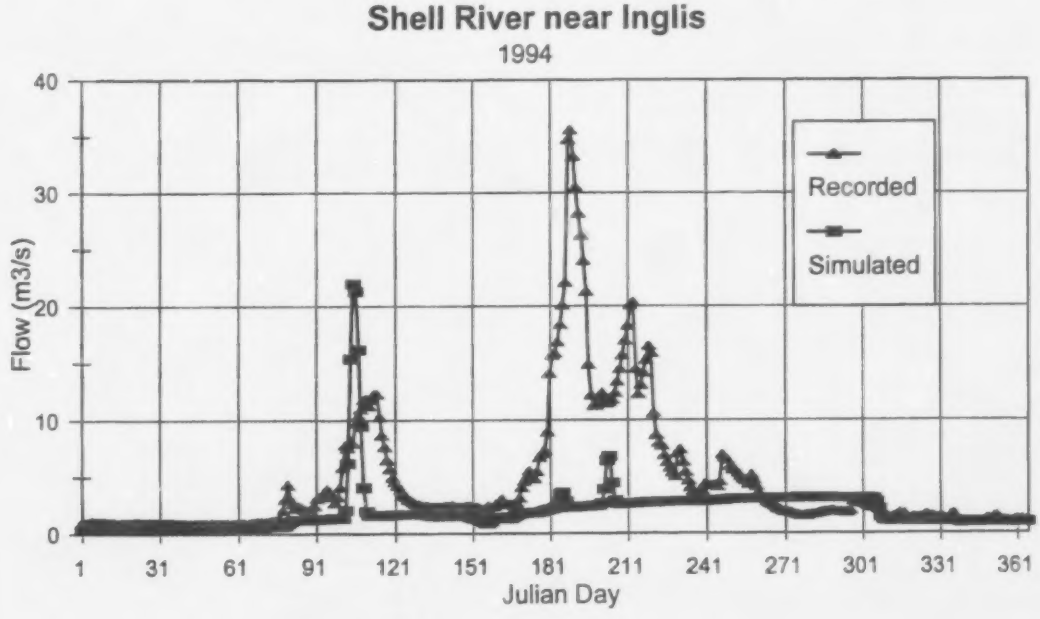


Figure 7.22
Shell River near Inglis - 1994



7.3.3.2 Other Stations

It is not unexpected that simulated flows for the Assiniboine River at Shellmouth show the same patterns as at Kamsack and the Shell River, both of which are upstream and account for a large portion of the drainage area to Shellmouth. Simulated flows in 1994 are quite poor, while very good matches are obtained in 1995, 1996, and 1997, as shown on the following table and in Figures 7.23 through 7.26.

Table 7.24 - Verification Results - Assiniboine River at Shellmouth

Year	Average Annual Flow (m^3/s)		Spring Peak Flow (m^3/s)		Date of Spring Peak Flow		R-Squared
	Recorded	Simulated	Recorded	Simulated	Recorded	Simulated	
1994	9.45	7.72	45.2	28.6	Apr 13	Apr 15	0.18
1995	43	48.7	708	603	Apr 25	May 8	0.56
1996	19.7	26.2	184	224	Apr 22	Apr 26	0.77
1997	18.4	28.6	307	252	Apr 27	Apr 23	0.90

Figure 7.23
Assiniboine River at Shellmouth - 1994

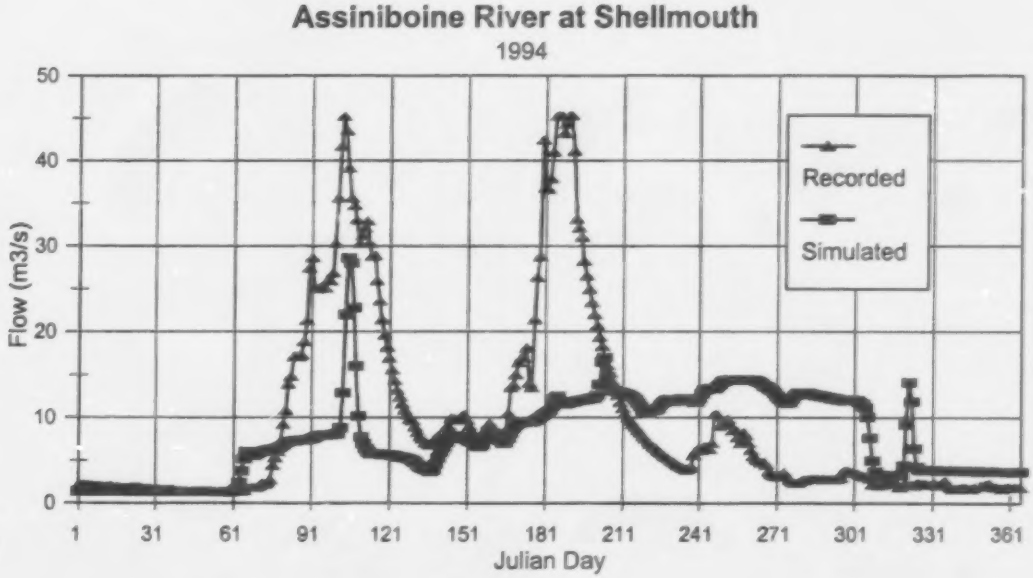


Figure 7.24
Assiniboine River at Shellmouth - 1995

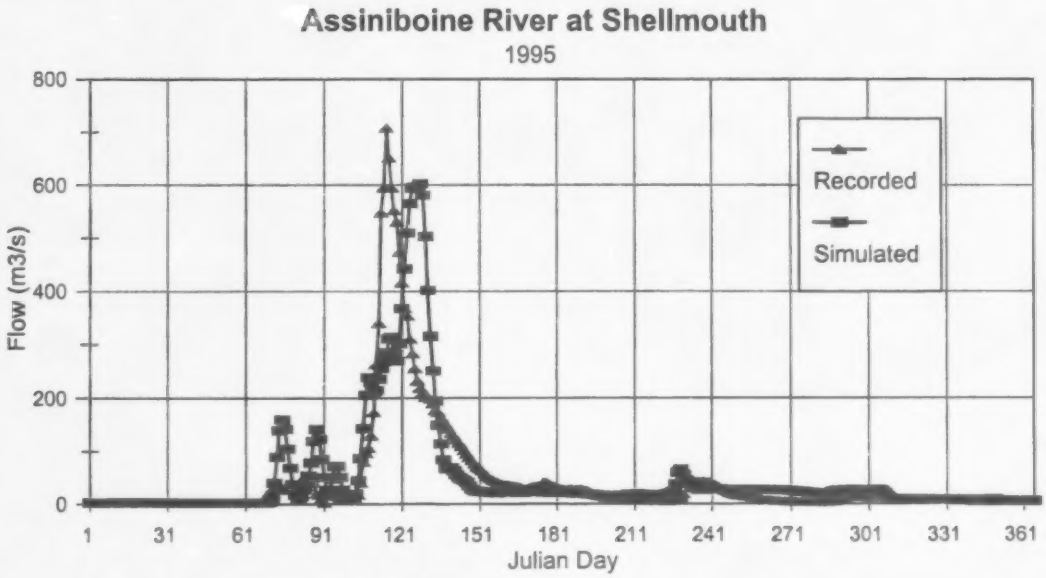


Figure 7.25
Assiniboine River at Shellmouth - 1996

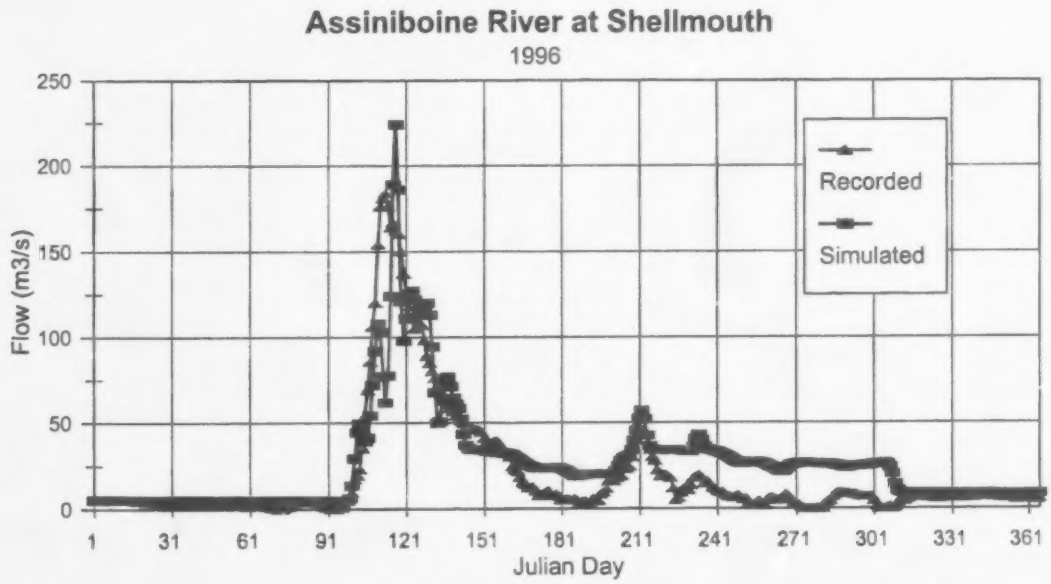
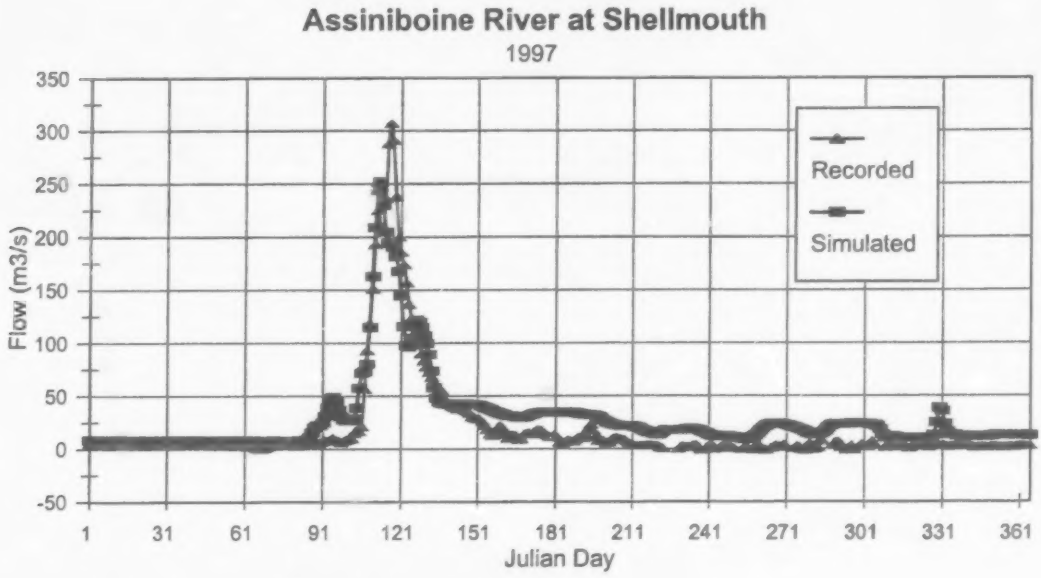


Figure 7.26
Assiniboine River at Shellmouth - 1997



Simulated flows at six other sites in the Basin were examined. These sites had gross drainage areas ranging from 76 km^2 up to 581 km^2. (In contrast, the four sites used to calibrate the model ranged in size from 1,930 km^2 up to 12,300 km^2.) Not unexpectedly, simulated flows at the six sites for 1994 had r-squared values from 0.00 to 0.11, and showed the same lack of response to spring snowmelt as shown in Figures 7.19 to 7.23.

Simulated flows at Crooked Hill Creek near Canora (581 km^2 gross drainage area) are compared to recorded flows in Figure 7.27 for 1997. No recorded flows are available for 1995 and 1996. The recorded flows for 1997 show an extreme flow of 41.7 m^3/s, the flood of record for that station. Simulations for that year show very little response to snowmelt. The r-squared value for 1997 was 0.20 and the simulated annual volume is nearly 60 percent greater than recorded. The Crooked Hill Creek watershed has been subject to extensive organized drainage development. Not having a land cover class for areas that have been drained may be one factor in the very poor performance of the model at this site in 1997.

Simulated flows at Stony Creek near Kamsack (456 km^2 gross drainage area) are compared to recorded flows in Figures 7.28 through 7.30 for 1995-97. Simulated spring peaks for 1995 and 1996 are more than three times greater than the recorded spring peaks, while in 1997 simulated peak is nearly half the recorded peak. Also of note in 1996 and 1997 hydrographs are the simulated summer base flows at about 1 m^3/s whereas the recorded flows recede to zero. Annual simulated volumes are more than double the recorded value in 1995 and more than triple the recorded values in 1996 and 1997. The r-squared values for 1995-97 are 0.25, 0.12, and 0.27 respectively.

Figure 7.27
Crooked Hill Creek near Canora - 1997

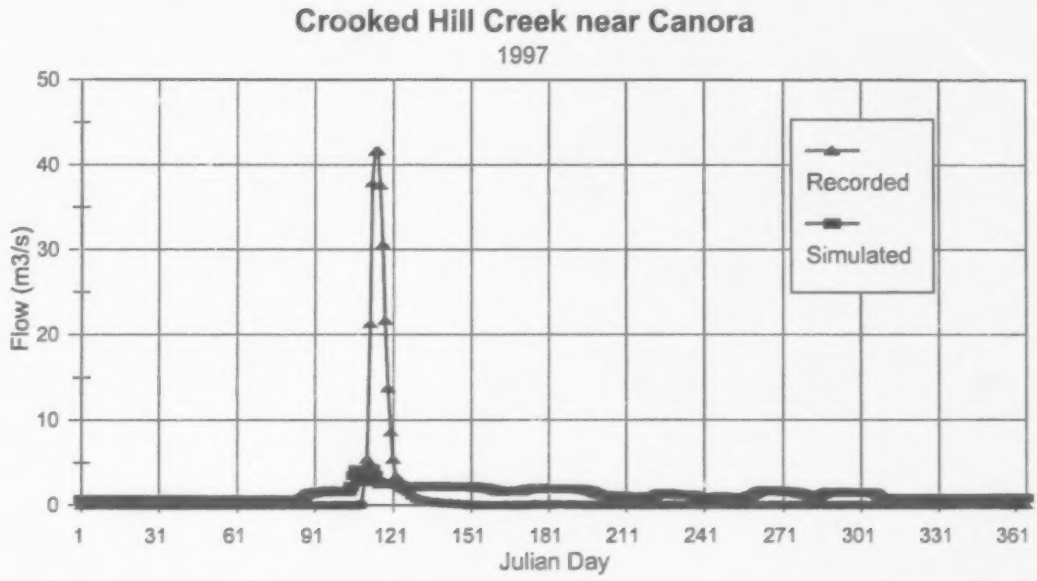


Figure 7.28
Stony Creek near Kamsack - 1995

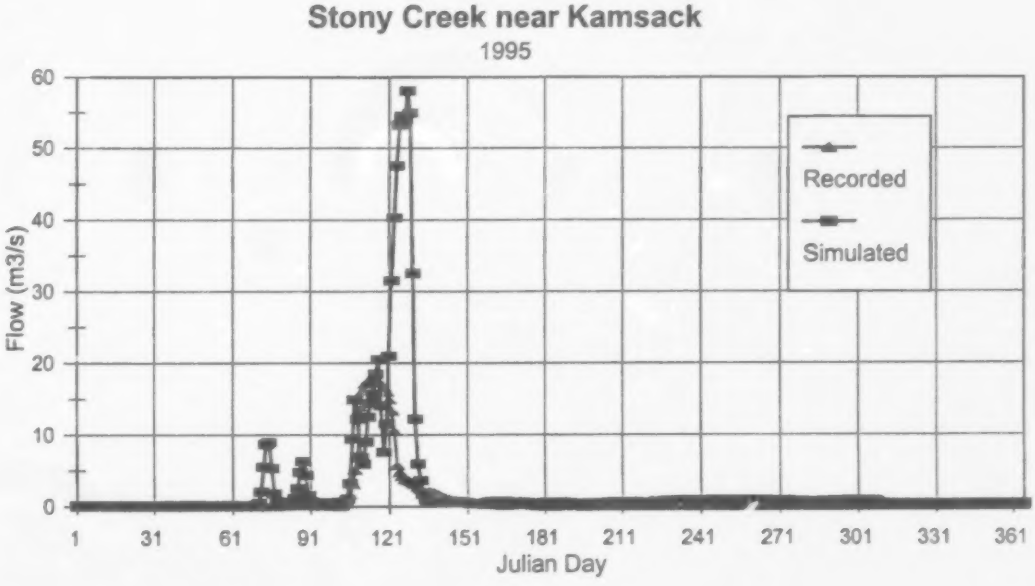


Figure 7.29
Stony Creek near Kamsack - 1996

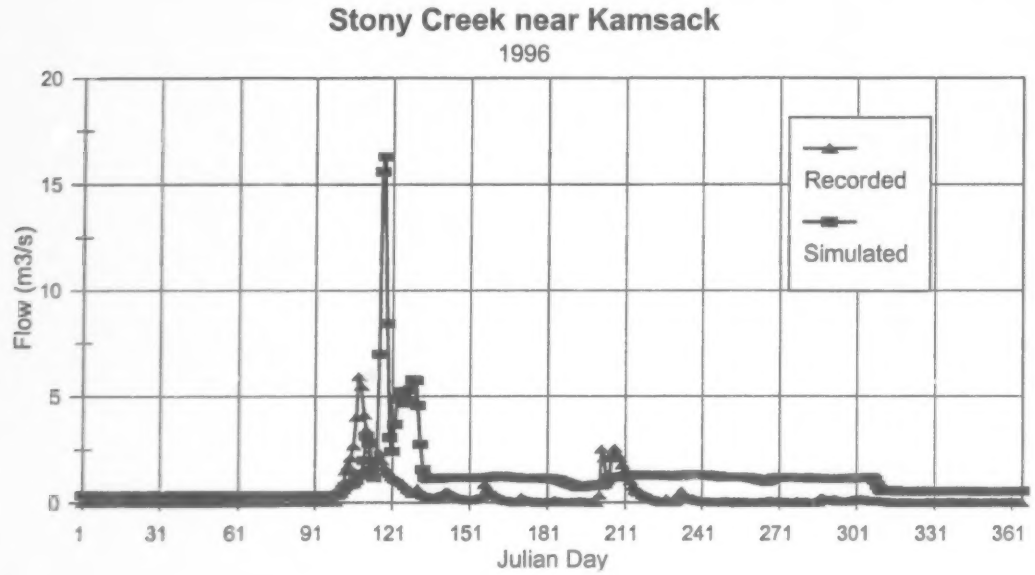
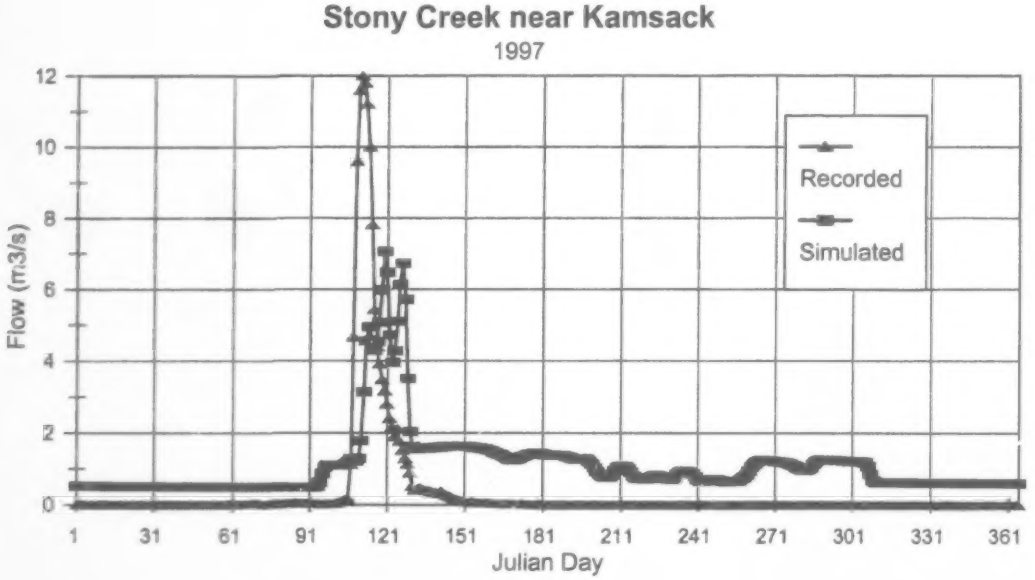


Figure 7.30
Stony Creek near Kamsack - 1997



Simulated flows at Smith Creek near Marchwell (439 km^2 gross drainage area) are compared to recorded flows in Figures 7.31 through 7.33 for 1995-97. The simulated spring peak for 1995 is more than double the recorded spring peak while in 1997 the simulated peak is nearly half the recorded peak. Also of note in 1996 and 1997 hydrographs are the simulated summer base flows at about 1 m^3/s whereas the recorded flows recede to zero. Annual simulated volumes are more than double the recorded values in 1995 and 1997, and more than triple the recorded value in 1996. The r-squared values for 1995-97 are 0.19, 0.27, and 0.53 respectively.

Figure 7.31
Smith Creek near Marchwell - 1995

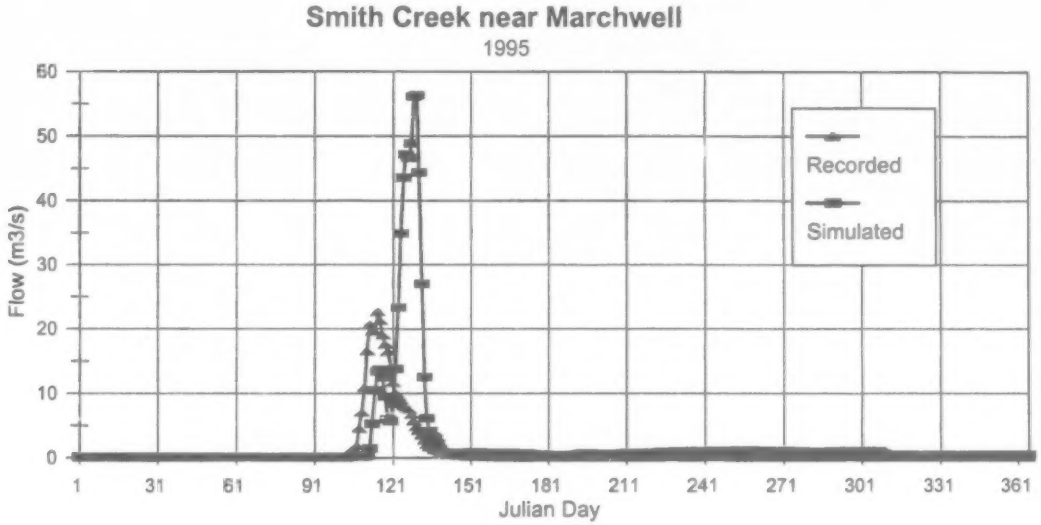


Figure 7.32
Smith Creek near Marchwell - 1996

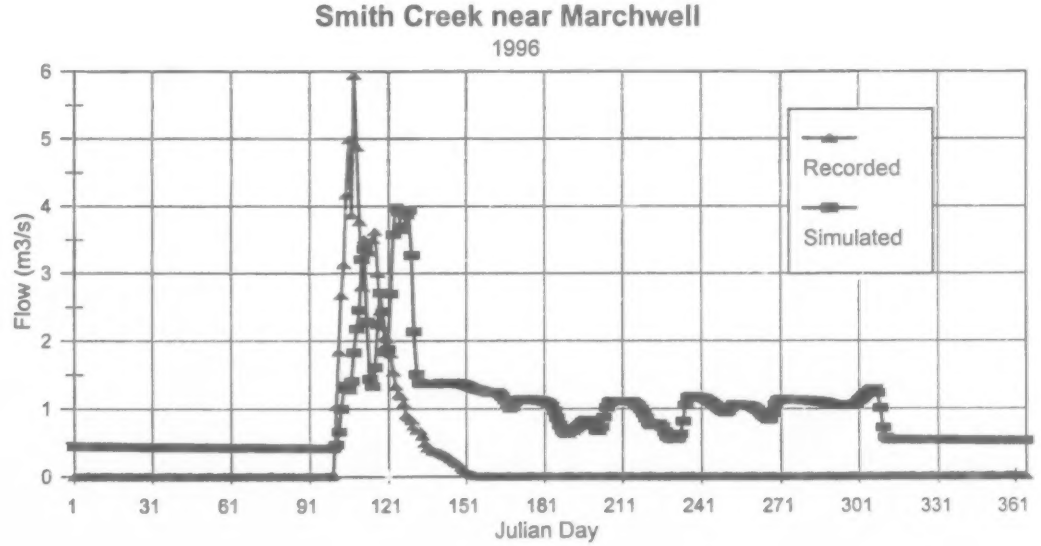
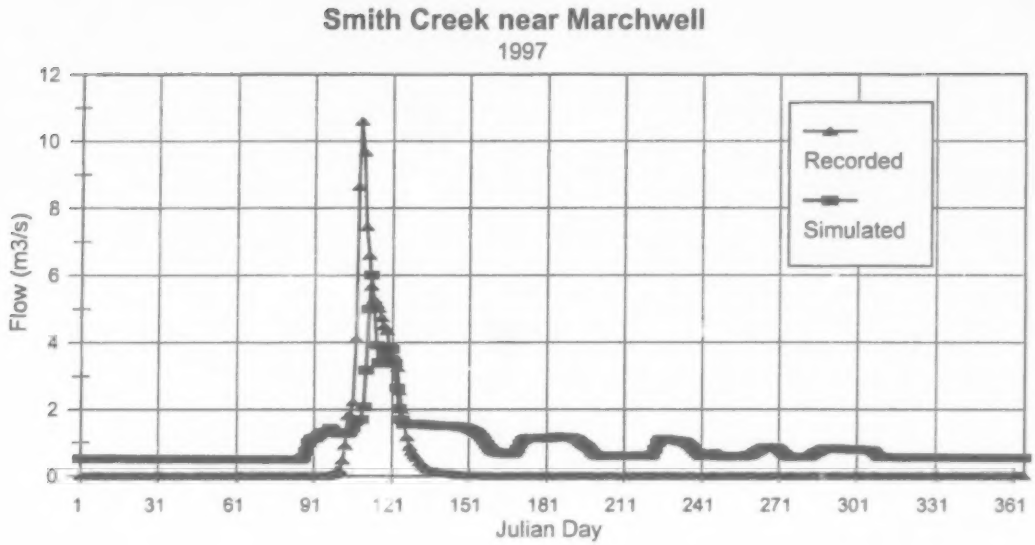


Figure 7.33
Smith Creek near Marchwell - 1997



Simulated flows at Willow Brook near Willowbrook (403 km^2 gross drainage area) are compared to recorded flows in Figures 7.34 through 7.36 for 1995-97. The simulated spring peaks for 1995 and 1997 are more than four times greater than the recorded spring peaks. Simulated summer base flows in the 1996 and 1997 hydrographs do show recessions down to zero flow, however the simulated base flows bump up to above 0.5 m^3/s in response to summer rainfall events. Annual simulated volumes are more than five times the recorded value in 1995, more than triple the recorded value in 1996, and more than seven times the recorded value in 1997. The r-squared values for 1995-97 are better than at the other stations at 0.29, 0.37 and 0.69 respectively.

Figure 7.34
Willow Brook near Willowbrook - 1995

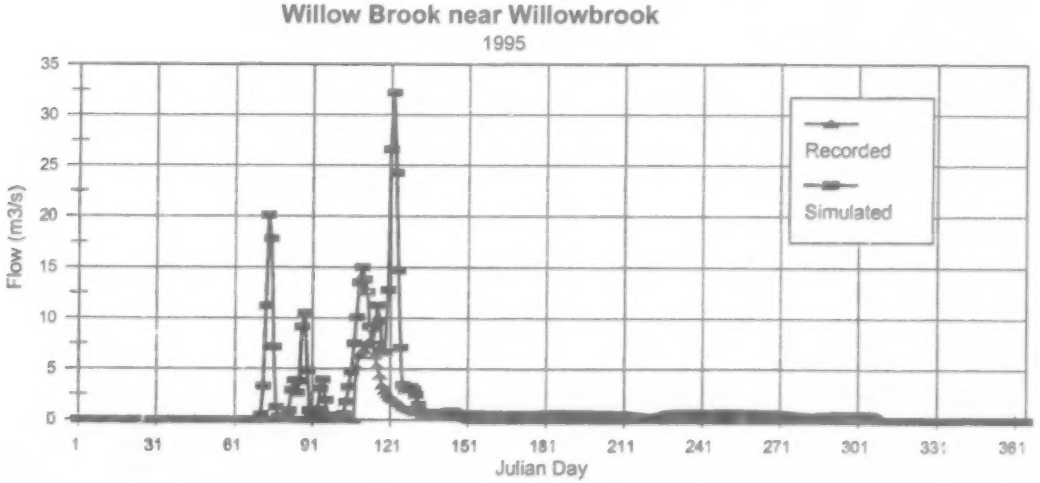


Figure 7.35
Willow Brook near Willowbrook - 1996

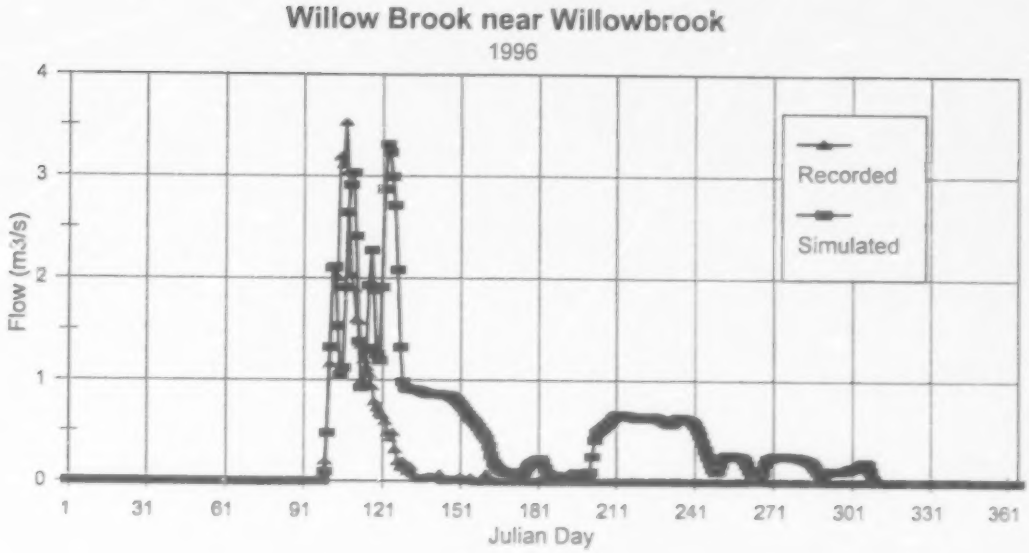
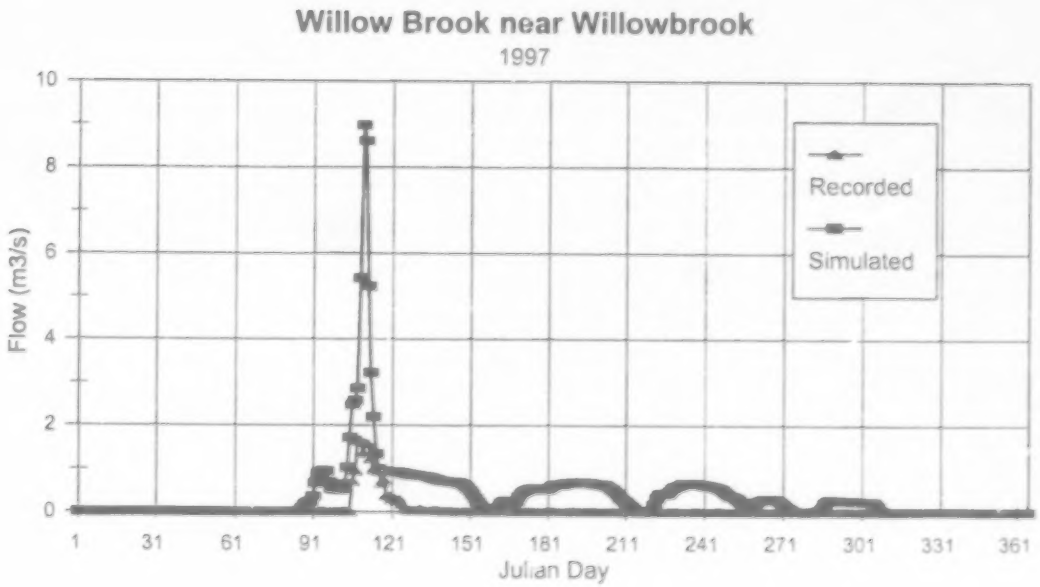


Figure 7.36
Willow Brook near Willowbrook - 1997



Simulated flows at Spirit Creek near Buchanan (260 km^2 gross drainage area) are compared to recorded flows in Figures 7.37 and 7.38 for 1995 and 1997. No recorded flows are available for 1996. The recorded flows for 1995 and 1997 show extreme flows which in the case of 1995 are more than double the simulated flow. The simulated flow in 1997 is similar to that of Crooked Hill Creek in that there is very little response to snowmelt. Annual simulated volumes are within 5 percent of the recorded value in 1995 but over 40 percent higher than the recorded value in 1997. The r-squared value for 1995 and 1997 are 0.21 and 0.11 respectively. The Spirit Creek watershed is similar to the Crooked Hill Creek watershed in that it also has been subject to extensive organized drainage development. Again, not having a land cover class for areas that have been drained may be one factor in the very poor performance of the model at this site.

Figure 7.37
Spirit Creek near Buchanan - 1995

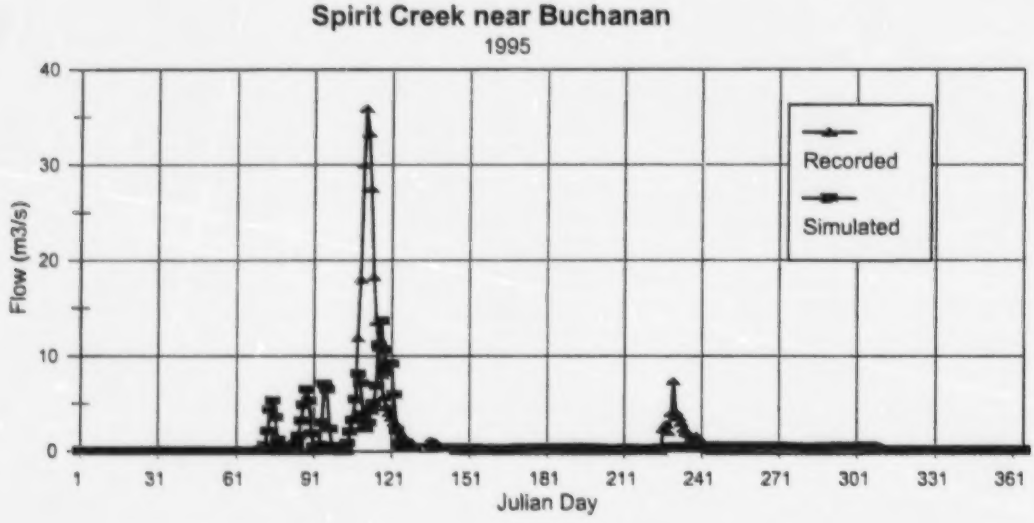
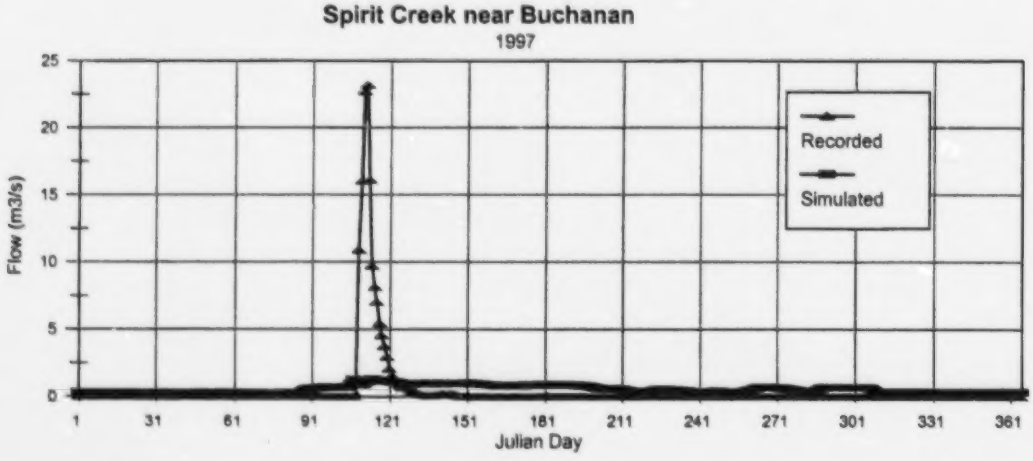


Figure 7.38
Spirit Creek near Buchanan - 1997



Simulated flows at Conjuring Creek near Russell (76 km^2 gross drainage area) are compared to recorded flows in Figures 7.39 through 7.41 for 1995-97. The simulated spring peaks for 1995 and 1997 are significantly less than the recorded spring peaks. Annual simulated volumes are with 30 percent of the recorded values in all three years. The r-squared values for 1995-97 are better than at most of the other stations at 0.17, 0.40, and 0.68 respectively.

Figure 7.39
Conjuring Creek near Russell - 1995

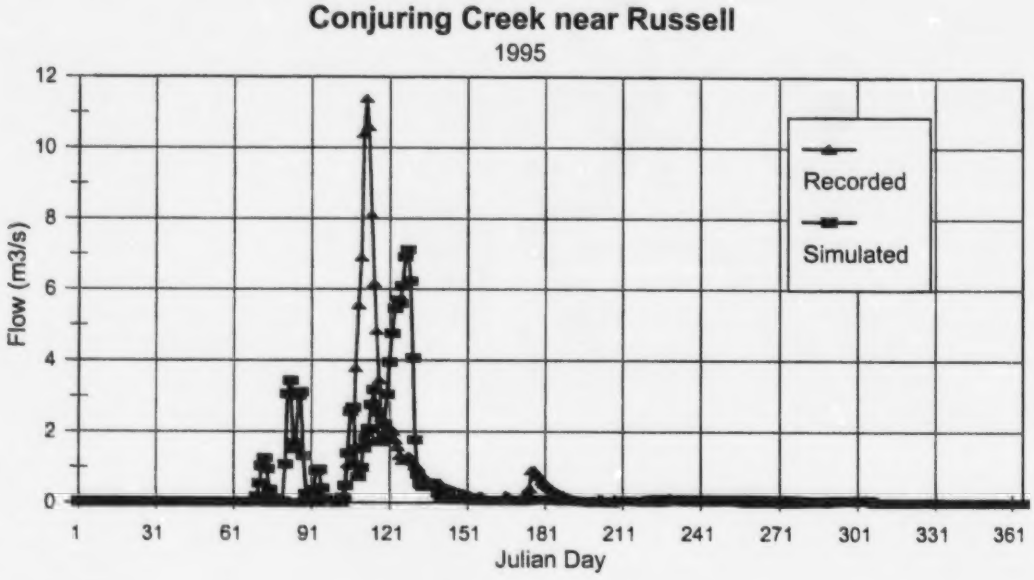


Figure 7.40
Conjuring Creek near Russell - 1996

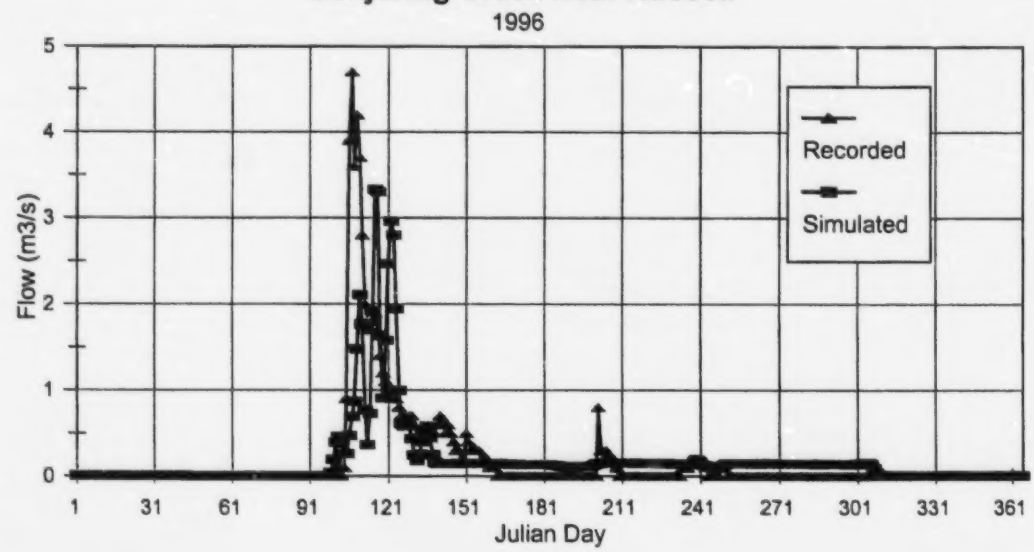
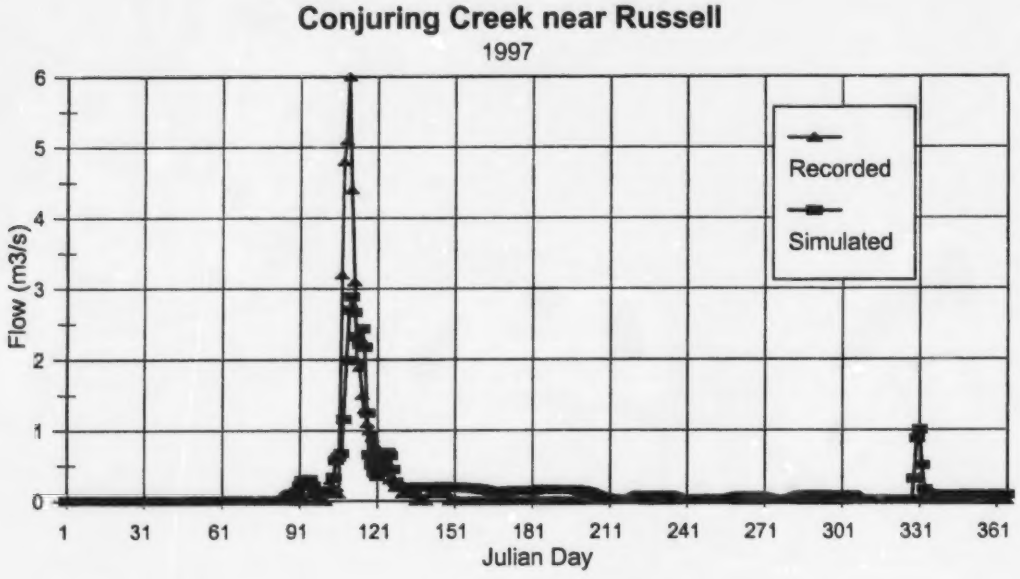


Figure 7.41
Conjuring Creek near Russell - 1997



The above discussion demonstrates that the model did not perform well at any of the stations for which the model was not calibrated. The exception being the Assiniboine River at Shellmouth, where flows are dominated by flows at two upstream sites which were calibrated; the Assiniboine River at Kamsack, and the Shell River near Inglis.

7.3.4 Sensitivity Testing and Results

In order to use the SLURP model for analyzing the effect of changes in land cover on the hydrologic response of the watershed, it was first necessary to test the sensitivity of the model to realistic changes in land cover. As discussed in Section 7.2 above, the original approach envisioned by the DFCC had been that an historic data set would be developed which would be comparable to the satellite based data set for the 1990s. This historic data set could then have been used to test the sensitivity of the model to land cover changes.

To test the sensitivity of the model to land cover changes, the DFCC opted to simply vary the land cover percentages shown in Table 7.3. However, rather than using an arbitrary or random approach to varying the percentages, a systematic approach was taken which would represent a realistic upper bound to historic land cover conditions. Canada Census data on "improved" and "unimproved" agricultural land by rural municipality from the 1956 and 1996 census were compared. Several assumptions were required to distribute the change in "improved" and "unimproved" agricultural land among the six land cover classes in SLURP. First, it was assumed that the large water body cover class would remain unchanged. Second, all land

converted from "unimproved" in the 1956 census to "improved" in the 1996 census was assumed to be converted to cropland. Last, it was assumed that each of the three remaining classes would contribute roughly the same proportion of area to the conversion of "unimproved" to "improved" land. The resulting percent areas are tabulated below. Table 7.25 lists the changes in terms of the percent area of each ASA, while Table 7.26 lists the changes in square kilometers.

Using the above assumptions, the Basin-wide 30 percent increase in crop area of 2,850 km^2 came from a 22 percent reduction in grass area (990 km^2), a 37 percent reduction in shrub area (650 km^2), a 23 percent reduction in wetland area (340 km^2), and a 23 percent reduction in bush area (870 km^2).

The land cover percent changes in Table 7.25 were applied on a cover at a time for the grass, shrub, wetland, and bush covers. In each case the crop cover was adjusted correspondingly. For example, in testing the sensitivity to change in grass cover, the percent grass in the Sheho ASA would be increased from 16 percent to 22 percent, with a corresponding reduction in the crop cover percentages from 62 percent to 56 percent. Because the land cover changes were based simply on Census data collected by RM, no attempt was made to distribute the changes of land cover within the ASA. It was assumed that the mean elevations, to-stream distances, in-stream distances, etc., remained the same as presented in Appendix I.

In testing the sensitivity of the calibrated model to an increase in grass cover, it was found that overall runoff volumes changed very little. The runoff volume at St. Lazare over the four year period 1994-97 was reduced by only 1.4 percent. Volume changes at individual stations and for individual years varied by up to 8.0 percent (reduction or increase). At all stations examined, a consistent pattern emerged with insignificant changes in 1994, slight peak and volume reductions in 1995, and generally slight increases in volume in 1996, and increases in peaks and volumes in 1997. Figures 7.42 through 7.45 compare annual simulated hydrographs for Crooked Hill Creek and are typical of the results for this sensitivity test.

Figure 7.42
Crooked Hill Creek near Canora - 1994

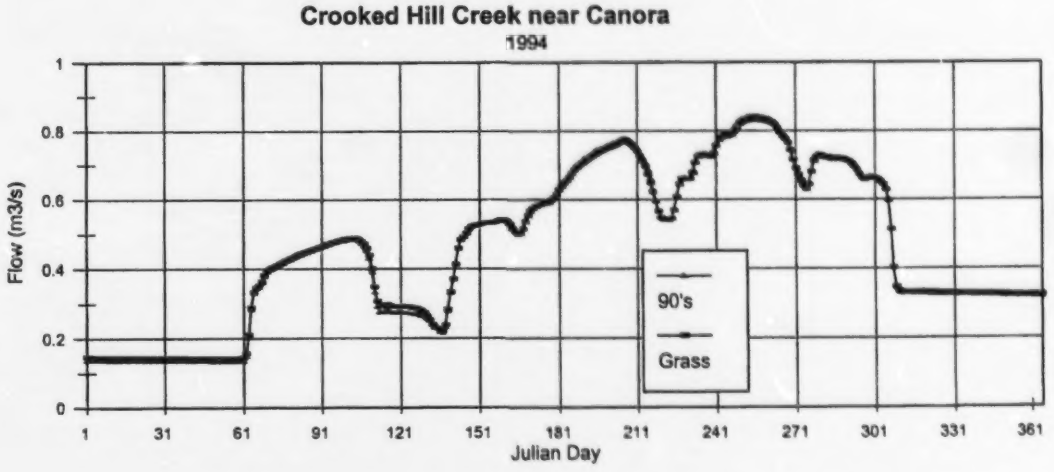


Figure 7.43
Crooked Hill Creek near Canora - 1995

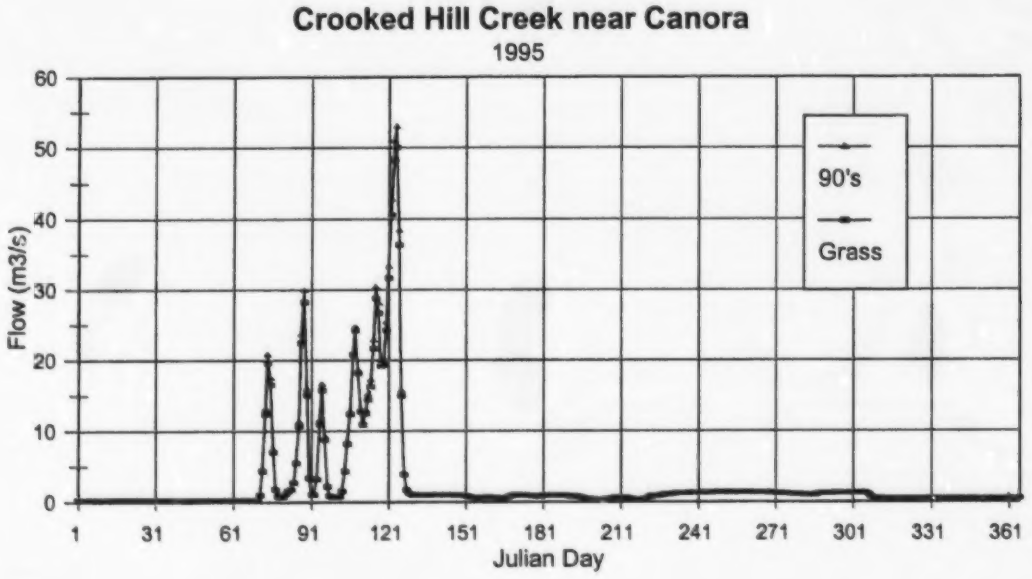


Figure 7.44
Crooked Hill Creek near Canora - 1996

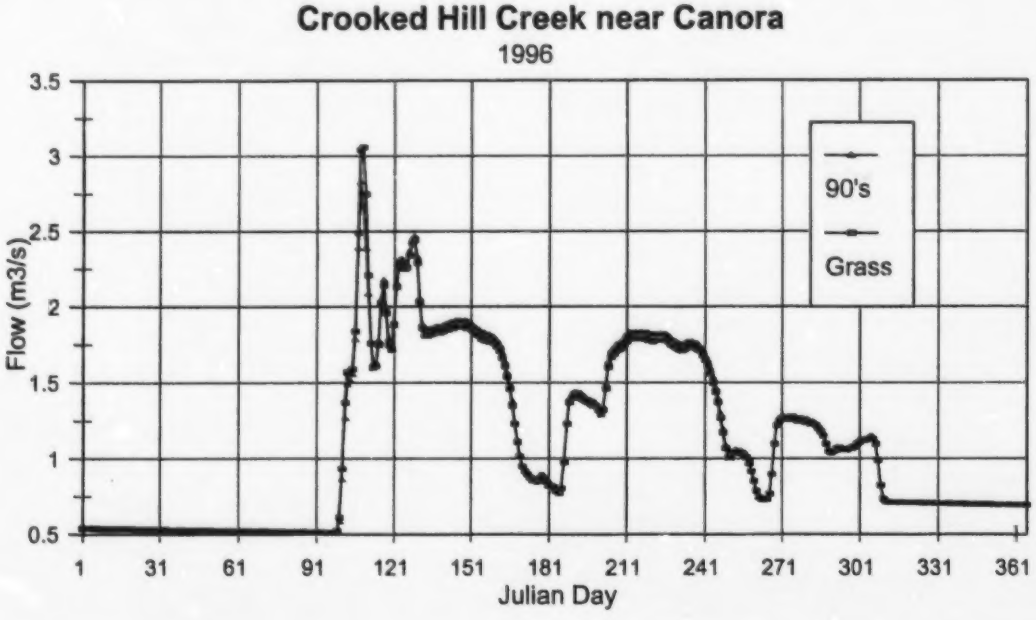
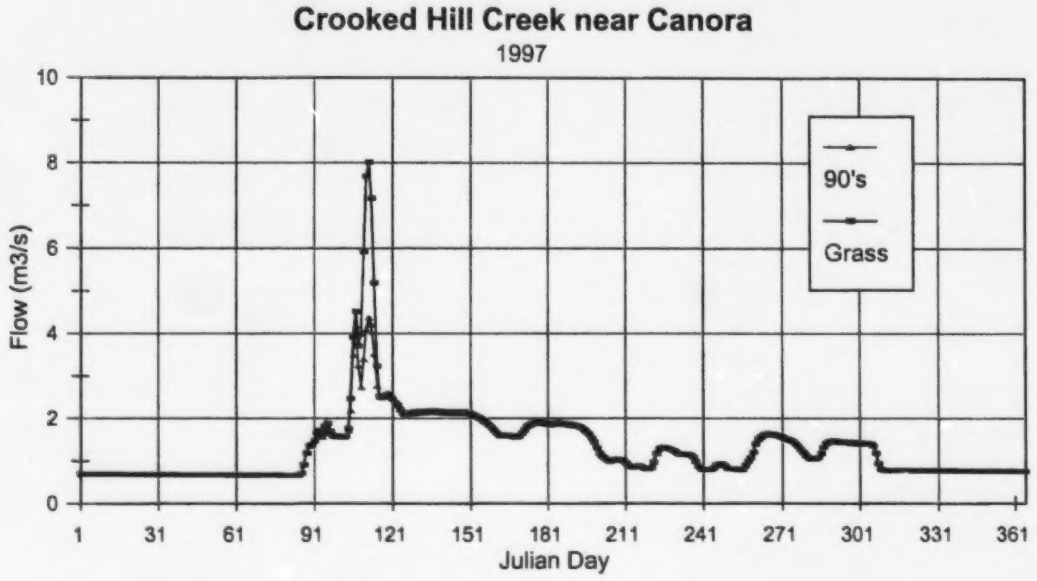


Figure 7.45
Crooked Hill Creek near Canora - 1997



The research discussed in Chapter 6 suggests that for increased grass cover and correspondingly reduced crop cover, the peaks and volumes would be consistently reduced. The test results for 1995 were consistent with the research, however the results for 1996 and 1997 were not. Part of the explanation for the 1997 results may lie in the selection of the infiltration class for the grass cover for 1997. With the selection of "limited" infiltration and a higher percent of the ASA area being grass, the 1997 peak snowmelt and volume increased.

In testing the sensitivity of the calibrated model to an increase in shrub cover, it was found that overall runoff volumes changed very little. The runoff volume at St. Lazare over the four year period 1994-97 was reduced by only 0.4 percent. Volume changes at individual stations and for individual years varied from a 10 percent reduction at Spirit Creek in 1995 to a 6.8 percent increase at Willow Brook in 1996. At all stations examined, a consistent pattern emerged with small volume increases in 1994, slight volume reductions in 1995, generally small increases in volume in 1996 and 1997. Peak flows at most stations and for most years were not significantly changed. The most visible change was in the summer base flows which tended to be higher and more responsive. This is likely attributable to the difference in the tank parameters for shrub and crop. Figures 7.46 through 7.49 compare annual simulated hydrographs for the Assiniboine River at St. Lazare.

Figure 7.46
Assiniboine river near St. Lazare - 1994

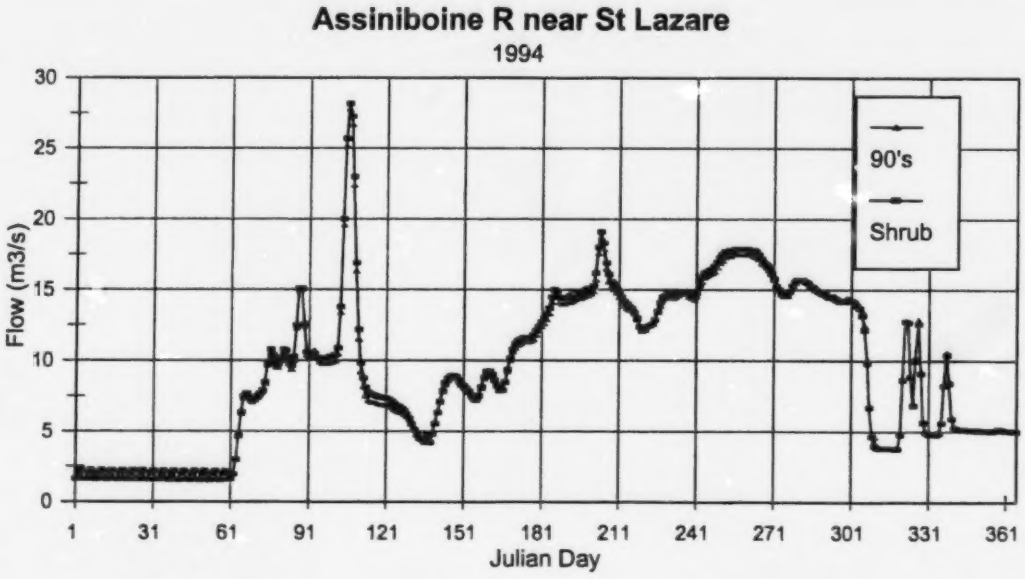


Figure 7.47
Assiniboine River near St. Lazare - 1995

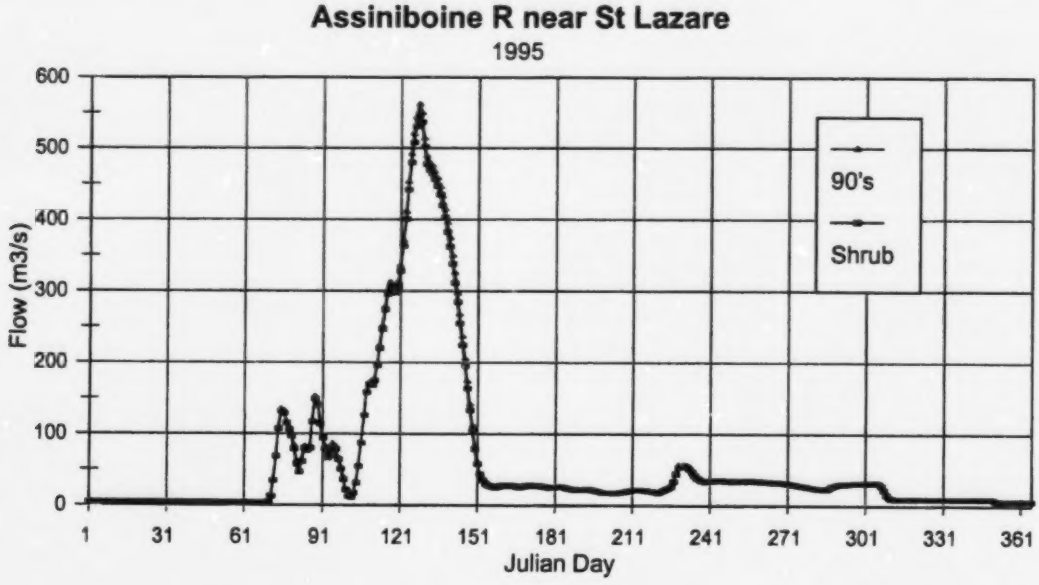


Figure 7.48
Assiniboine River near St. Lazare - 1996

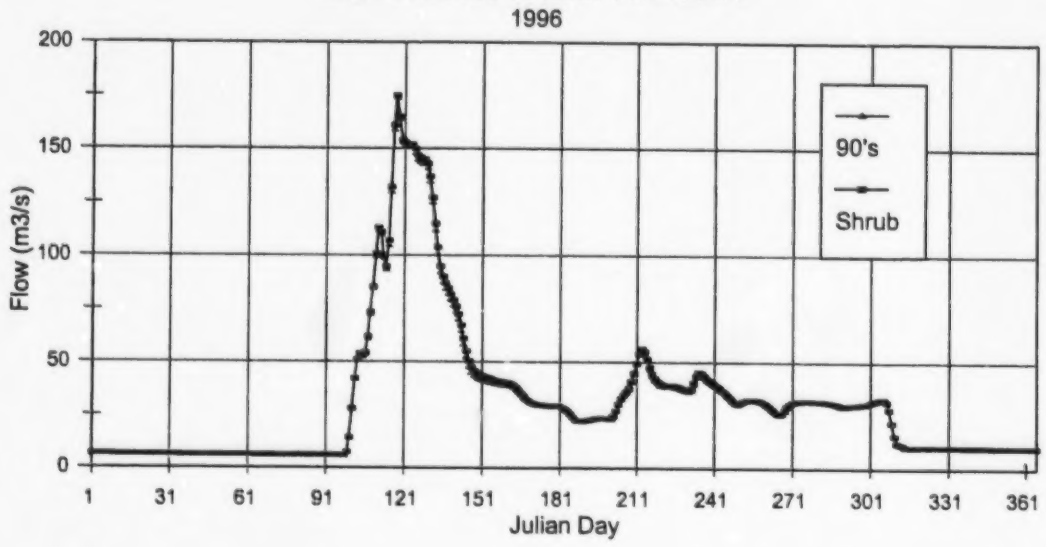
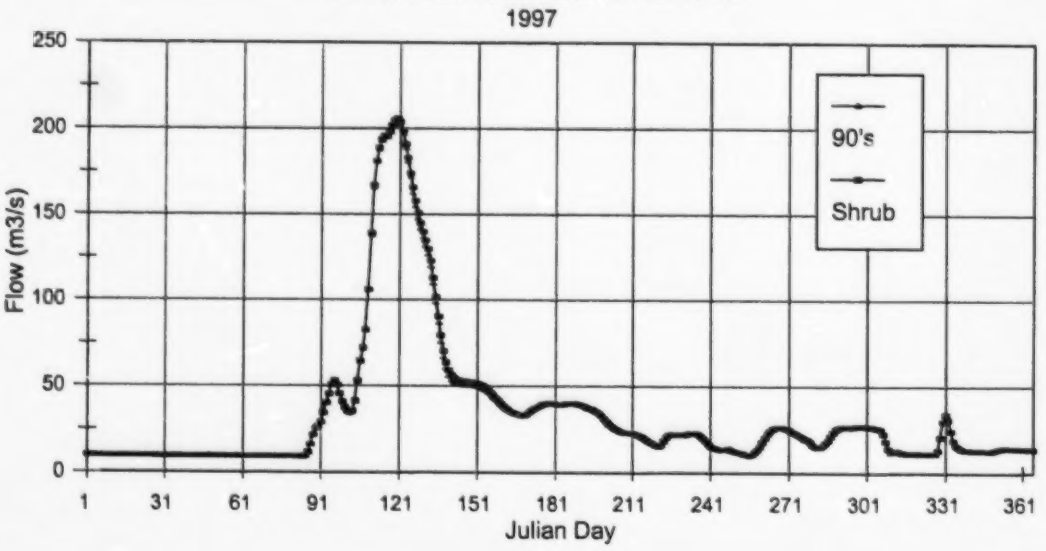


Figure 7.49
Assiniboine River near St. Lazare - 1997



The research discussed in Chapter 6 suggests that for increased shrub cover and correspondingly reduced crop cover, the peaks and volumes would be consistently reduced. The test results were not consistent with the research.

In testing the sensitivity of the calibrated model to an increase in wetland cover, it was found that overall runoff volumes changed very little. The runoff volume at St. Lazare over the four year period 1994-97 was reduced by only 1.0 percent. Volume changes at individual stations and for individual years varied by up to 9 percent (reduction or increase). At all stations examined, a consistent pattern emerged with small reductions in 1994, no significant changes in either peaks or volume in 1995, increases in peaks and volumes in 1996 and 1997. Some of the increases in peaks for 1996 were quite large. Figures 7.50 through 7.53 compare annual simulated hydrographs for Stony Creek and are typical of the results for this sensitivity test.

Figure 7.50
Stony Creek near Kamsack - 1994

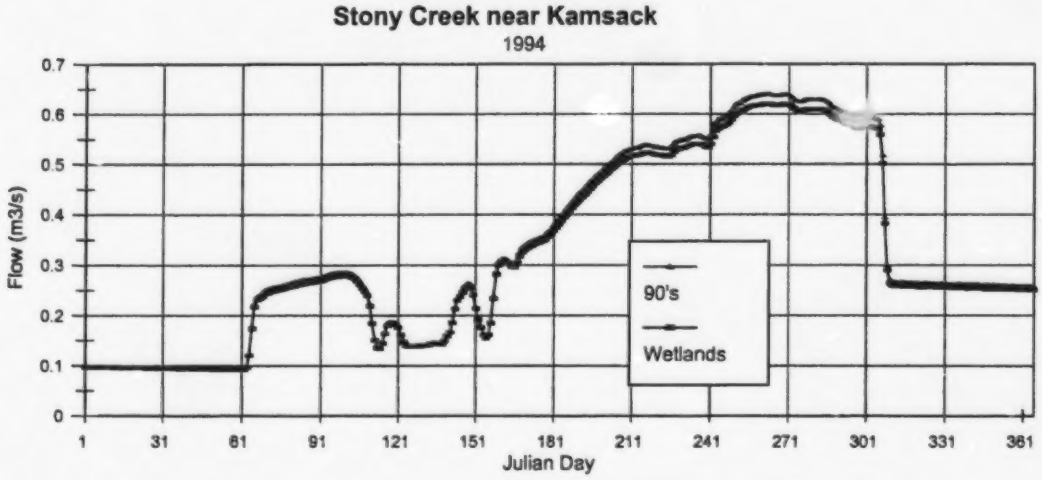


Figure 7.51
Stony Creek near Kamsack - 1995

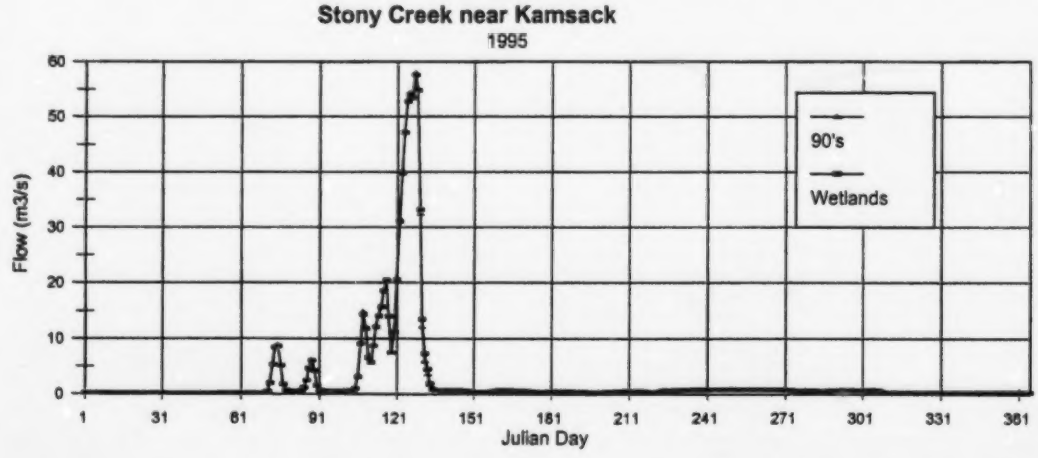


Figure 7.52
Stony Creek near Kamsack - 1996

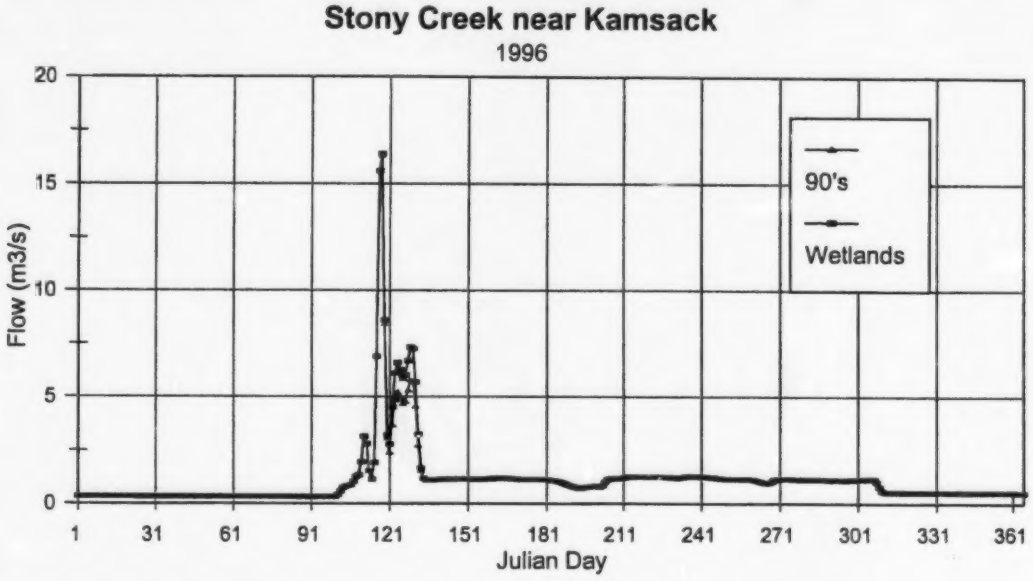
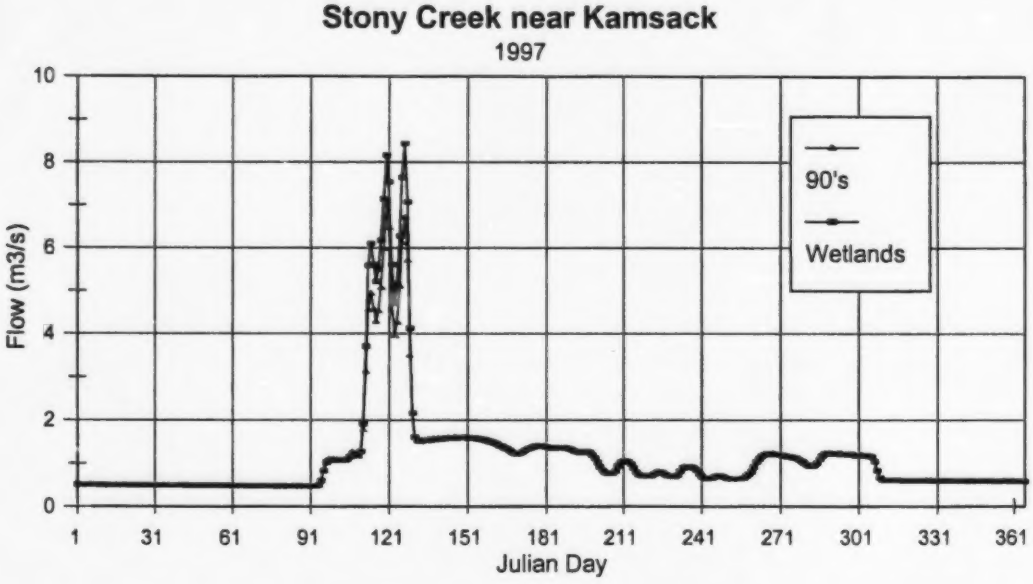


Figure 7.53
Stony Creek near Kamsack - 1997



The discussions presented in Section 6.4 suggest that for increased wetland cover and correspondingly reduced crop cover, the peaks and volumes would be reduced. The test results were inconsistent with no trend or pattern.

In testing the sensitivity of the calibrated model to change in bush cover, it was found that overall runoff was consistently reduced and the reductions were generally in proportion to the magnitude of increase in bush cover and corresponding reduction in crop cover. The runoff volume at St. Lazare over the four year period 1994-97 was reduced by 2.9 percent. Volume changes at individual stations and for individual years varied from zero up to 10 percent reduction at Spirit Creek in 1995. At all stations examined, a consistent pattern emerged with volume reductions in each year and with peak flow reductions in 1995. Peak flows in 1996 and 1997 were not significantly changed except at stations with a relatively large change from crop to bush percentage (e.g., Crooked Hill and Spirit creeks). Figures 7.54 through 7.57 compare annual simulated hydrographs for Crooked Hill Creek which is one of the most heavily affected stations with bush cover tripled in the test case from five percent of ASA area to 15 percent.

Figure 7.54
Crooked Hill Creek near Canora - 1994

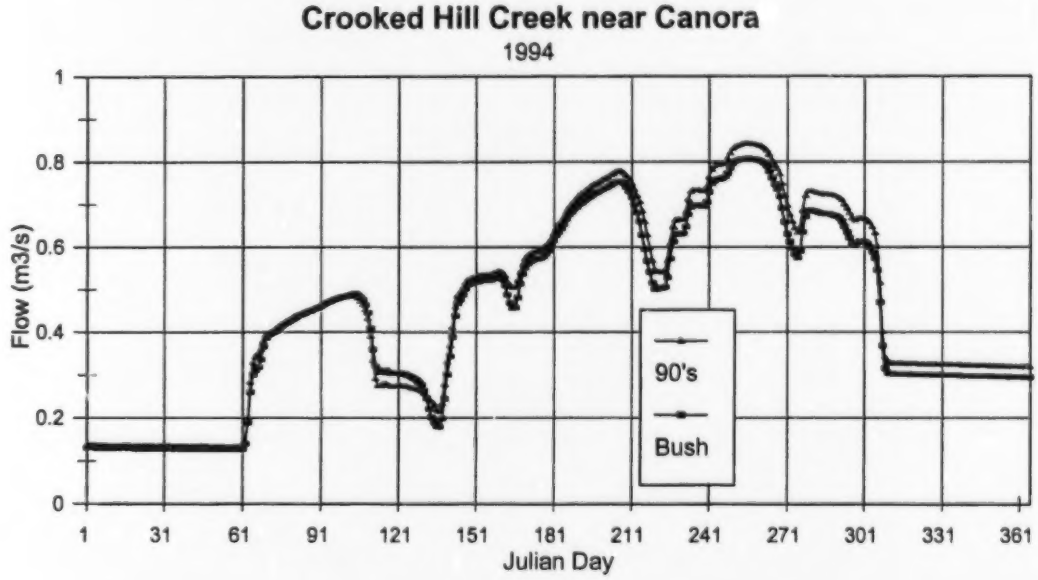


Figure 7.55
Crooked Hill Creek near Canora - 1995

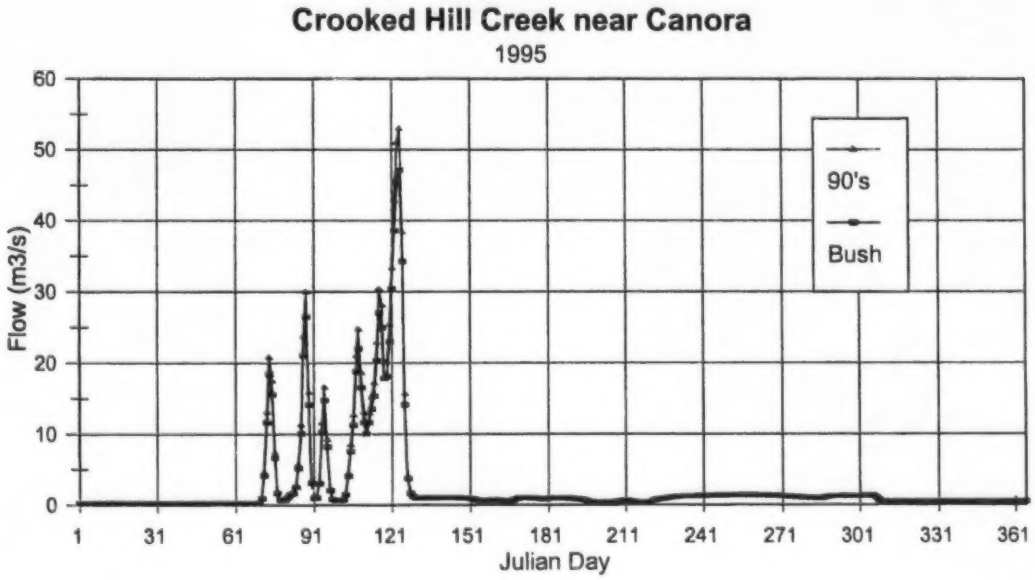


Figure 7.56
Crooked Hill Creek near Canora - 1996

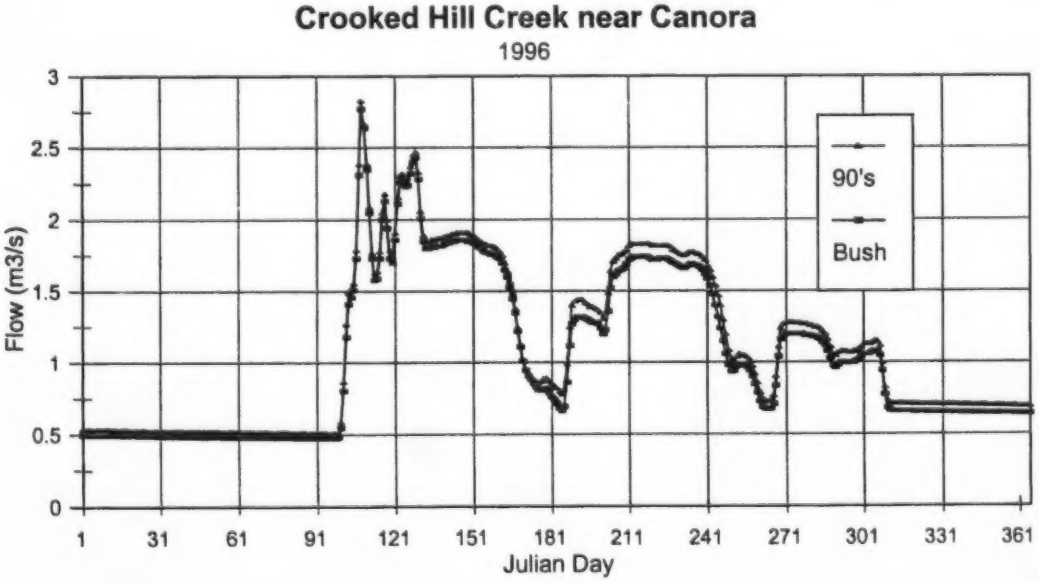
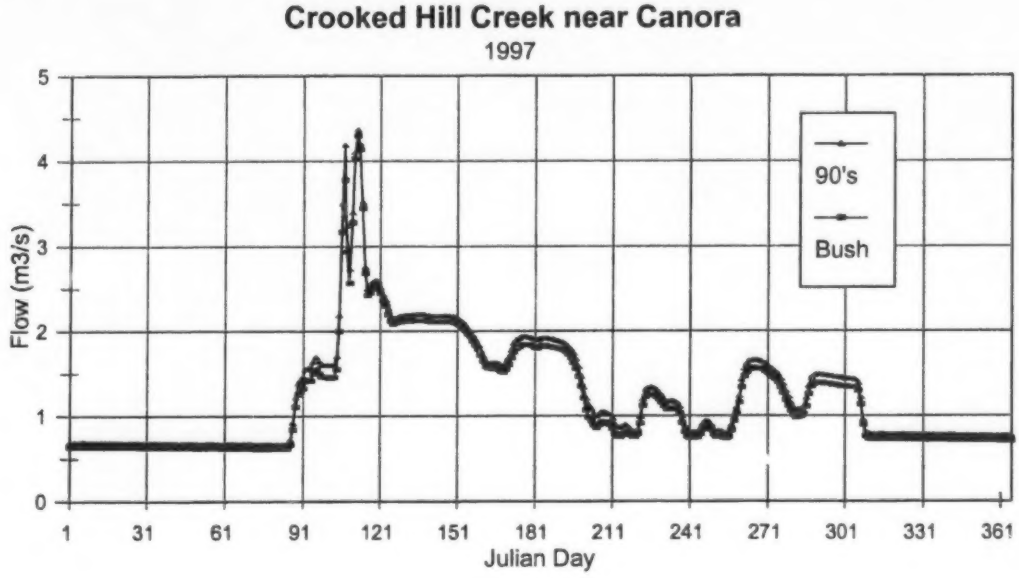


Figure 7.57
Crooked Hill Creek near Canora - 1997



The research suggests that when increasing bush cover and correspondingly reducing crop cover the peaks and volumes would be consistently reduced. The test were consistent with the research, however the magnitude of the flow reductions were generally insignificant.

Overall, the DFCC felt that the results of the sensitivity testing were not consistent. Even when the sensitivities were consistent with the research, they were generally not significant in magnitude. Based on a thorough review of the results of each test for each station in addition to the results presented above, the DFCC's opinion was that the model was not sufficiently reliable to form conclusions as to the effect of land cover change on Basin hydrology. Recommendations on possible follow-up work on the SLURP model are presented in the following section.

Table 7.25 - Sensitivity Testing - Land Cover Change (percent)

ASA	Crop			Grass			Shrub			Wetland			Bush		
	90s	50s	diff	90s	50s	diff	90s	50s	diff	90s	50s	diff	90s	50s	diff
WSR near Sheho	62	49	13	16	22	-6	10	14	-4	3	4	-1	7	9	-2
WSR to Theodore Reservoir	62	42	20	18	24	-6	9	15	-6	3	4	-1	7	14	-7
WSR to confluence with Yorkton Creek	55	36	19	23	30	-7	11	15	-4	4	4	0	7	15	-8
Willow Brook	40	22	18	26	28	-2	16	24	-8	6	6	0	12	20	-8
Cussed Creek	52	38	14	26	30	-4	12	15	-3	5	7	-2	5	10	-5
Yorkton Creek	70	56	14	17	25	-8	4	6	-2	4	6	-2	4	6	-2
Spirit Creek	88	52	36	1	4	-3	6	24	-18	1	4	-3	4	16	-12
Good Spirit Creek	42	28	14	27	28	-1	8	12	-4	4	6	-2	11	18	-7
WSR near Canora	72	59	13	15	20	-5	2	4	-2	6	8	-2	4	8	-4
Assiniboine R near Sturgis	41	28	13	11	12	-1	9	12	-3	7	8	-1	31	39	-8
Crooked Hill Creek near Canora	86	59	27	3	8	-5	5	15	-10	1	3	-2	5	15	-10
Assiniboine R at Kamsack	69	61	8	15	18	-3	3	4	-1	6	8	-2	7	9	-2
Little Boggy Creek	25	15	10	16	15	1	4	6	-2	8	9	-1	47	55	-8
Stony Creek near Kamsack	86	59	27	0	9	-9	0	8	-8	9	12	-3	5	12	-7
Shell River near Roblin	5	5	0	8	8	0	0	0	0	16	16	0	70	70	0
Shell River near Inglis	38	20	18	32	37	-5	0	5	-5	5	7	-2	25	31	-6
Local area east of Lake of Prairies	58	56	2	23	24	-1	5	5	0	3	3	0	11	12	-1
Local area west of Lake of Prairies	65	59	6	19	22	-3	5	6	-1	5	6	-1	6	7	-1
Conjuring Creek near Russell	54	48	6	23	25	-2	0	2	-2	5	5	0	18	20	-2
Smith Creek	79	46	33	6	16	-10	4	10	-6	6	15	-9	5	13	-8
Local area east side above Russell	58	49	9	27	33	-6	1	1	0	3	4	-1	11	13	-2
Local area west side above Russell	70	46	24	12	22	-10	5	9	-4	5	9	-4	8	14	-6
Deerhorn Creek, local area west side above St. Lazare	63	45	18	19	28	-9	6	9	-3	3	5	-2	9	13	-4
Local area east side above Assiniboine R near St. Lazare	64	49	15	21	29	-8	0	2	-2	4	5	-1	11	15	-4

Table 7.26 - Sensitivity Testing - Land Cover Change in Square Kilometres

ASA	Crop			Grass			Shrub			Wetland			Bush		
	90s	50s	diff	90s	50s	diff	90s	50s	diff	90s	50s	diff	90s	50s	diff
WSR near Sheho	1194	944	250	308	424	-116	193	270	-77	58	77	-19	135	173	-39
WSR to Theodore Reservoir	370	250	119	107	143	-36	54	89	-36	18	24	-6	42	83	-42
WSR to confluence with Yorkton Creek	139	91	48	58	76	-18	28	38	-10	10	10	0	18	38	-20
Willow Brook	161	89	72	105	113	-8	64	97	-32	24	24	0	48	81	-32
Cussed Creek	537	393	145	269	310	-41	124	155	-31	52	72	-21	52	103	-52
Yorkton Creek	1626	1301	325	395	581	-186	93	139	-46	93	139	-46	93	139	-46
Spirit Creek	229	135	94	3	10	-8	16	62	-47	3	10	-8	10	42	-31
Good Spirit Creek	237	158	79	152	158	-6	45	68	-23	23	34	-11	62	102	-40
WSR near Canora	1059	868	191	221	294	-74	29	59	-29	88	118	-29	59	118	-59
Assiniboine R near Sturgis	790	539	250	212	231	-19	173	231	-58	135	154	-19	597	751	-154
Crooked Hill Creek near Canora	500	343	157	17	47	-29	29	87	-58	6	17	-12	29	87	-58
Assiniboine R at Kamsack	1171	1036	136	255	306	-51	51	68	-17	102	136	-34	119	153	-34
Little Boggy Creek	64	38	25	41	38	3	10	15	-5	20	23	-3	120	140	-20
Stony Creek near Kamsack	392	269	123	0	41	-41	0	36	-36	41	55	-14	23	55	-32
Shell River near Roblin	66	66	0	106	106	0	0	0	0	213	213	0	930	930	0
Shell River near Inglis	253	133	120	213	246	-33	0	33	-33	33	47	-13	167	206	-40
Local area east of Lake of Prairies	589	569	20	234	244	-10	51	51	0	30	30	0	112	122	-10
Local area west of Lake of Prairies	734	666	68	214	248	-34	56	68	-11	56	68	-11	68	79	-11
Conjuring Creek near Russell	41	36	5	17	19	-2	0	2	-2	4	4	0	14	15	-2
Smith Creek	347	202	145	26	70	-44	18	44	-26	26	66	-39	22	57	-35
Local area east side above Russell	233	197	36	109	133	-24	4	4	0	12	16	-4	44	52	-8
Local area west side above Russell	412	270	141	71	129	-59	29	53	-24	29	53	-24	47	82	-35
Local area west side above St. Lazare	671	479	192	202	298	-96	64	96	-32	32	53	-21	96	138	-43
Local area east side above St. Lazare	494	378	116	162	224	-62	0	15	-15	31	39	-8	85	116	-31

7.4 Chapter Summary and Conclusions

7.4.1 Modeling Findings

Data incompatibility issues combined with inadequate time and resources prevented the quantification of drainage activity and wetland loss. Without historic data on wetlands and drainage, the SLURP model could not be used to assess the impact of drainage.

One of the primary issues that the DFCC was asked to address was that of the impact of agricultural drainage on peak flows and flow volumes in the Assiniboine River. One obstacle encountered in attempting to address this question was that there is no economical method available to detect and map agricultural drainage on the scale of the Basin. This obstacle needs to be addressed if the effect of drainage projects are to modeled on the scale of the Basin.

SLURP performed reasonably well in the calibration and verification but gave unreliable results in the sensitivity testing phase. Therefore, the model could not be used to address the issue of the impact of land use change on the hydrologic response of the Basin.

The model and necessary data sets will be distributed to the participating agencies for continued development and application. It is recommended that an inter-agency working group be formed to continue work on modeling of watershed drainage and land cover change.

7.4.2 Recommendations for Hydrologic Model Development

During the model calibration process, it became apparent to the DFCC that while the PBS-SLURP could likely be made to simulate the Assiniboine watershed, at least two important inter-related prairie hydrologic processes were missing from the model. In general, the two processes are: 1) the flow of surface runoff and interflow from one land cover type to another prior to reaching the stream network, and 2) the variation of surface area contributing to streamflow in any given year due to storage of runoff in wetlands and surface depressions.

The central issue in modeling the Basin was that the landscape has innumerable small wetlands. Each individual wetland has at least a small contributing upland. In many years, the evaporation from, and storage in, the wetland is sufficient to prevent any contribution to streamflow out of the wetland reaching the stream network. However in some years, such as 1995, a combination of high wetland storage carry-over, winter and early spring precipitation, temperature and radiation conditions during snowmelt, and frozen soil conditions will result in many wetlands all contributing to the spring snowmelt runoff peak.

Further improvements to the hydrologic model could be made in the handling of percolation of groundwater into deep aquifers which do not return water to the source watershed within the same geologic time scale.

Another improvement could be made in the calculation of evaporation from small water bodies embedded in a dryland environment. For these water bodies, the evaporation rate likely approaches the potential evaporation rate until the water body dries out. A revision was made to the PBS-SLURP which reduces the Granger evaporation equation to a simpler form of the Priestley-Taylor potential evaporation equation for specified land cover types.

Finally, a further improvement could be made by adding additional options for the calculation of evaporation over large water bodies from the single option now available, namely the Morton Complementary Lake Evaporation method.

In light of the experience gained by the DFCC during the course of this Study, a number of recommendations for research agencies to consider were developed with the aim of improving the simulation of hydrologic processes in the Canadian Prairies in models available to hydrologists. These recommendations are:

- Research continue on the development of a hydrologic model that simulates hydrologic processes in the Canadian environment which includes conditions and processes for the Canadian Prairies. Such a model would have the following features:
- It would incorporate the Blowing Snow, Frozen Soil Infiltration, Winter Evaporation, and Winter Soil Drainage components used in this Study.
- It would have a component which simulates the movement of surface runoff and interflow from one land cover to another prior to reaching the stream network (e.g., flow from an upland area flowing into a wetland).
- It would have a component which simulates the variability of the area contributing to streamflow as occurs in many prairie watersheds.
- It would allow the representation of percolation to deep groundwater storage which does not return flow back to the watershed within the time scales being modeled.
- It would simulate evaporation from small open-water or saturated surfaces at or near the potential evaporation rate of the surrounding drier land environment.
- It would have several scientifically acceptable methods of calculating evaporation from large bodies of water.
- Research be done to develop cost-effective methods of remotely sensing and mapping land covers which have been altered by agricultural drainage in the Canadian Prairies. The alteration of these land covers are suspected to have a significant effect on prairie hydrology in at least some years. However, conclusive determination of their effect is precluded until they can be detected and mapped.

8 Conclusions and Recommendations

Each of the following sections summarizes the issue specific findings and conclusions of the Drainage and Flood Control Committee. Also in each section are recommendations which are either carried forward from previous sections in this report or were developed by the DFCC subsequent to the compilation of all the issues and findings in the report. The recommendations, while addressing specific issues, can be regarded as falling into one or more of the following strategies:

- Watershed Management Plans;
- Best Management Practices;
- Policy and Legislation;
- Compliance and Enforcement;
- Education and Demonstration;
- Research;
- Monitoring and Assessment; and
- Incentive Programs.

8.1 Major Floods

Findings:

The DFCC found that the high flows of 1995 can be primarily attributed to a combination of meteorological events, namely wet antecedent conditions, an above-normal snowpack, and a mid-April rainstorm which contributed additional runoff water and caused rapid melting of the snowpack. This rapid melt across much of the Basin resulted in an unusual hydrologic condition. That was the nearly coincident peak flows on the Assiniboine and Whitesand rivers at Kamsack, as well as on smaller local tributaries between Kamsack and Shellmouth Dam.

Observations of the 1995 flood clearly showed that during the period of high streamflow, high levels in the receiving streams prevented or delayed flow in many drainage ditches. Similarly, field observations in the fall of 1994 indicated that the high precipitation had filled many of the natural wetlands and that the soil moisture levels were high. These factors reduced the storage available to retain snowmelt runoff in the spring of 1995. The natural wetland storage available was then very small relative to the extreme runoff that occurred in 1995.

Similar meteorologic conditions resulted in a major flood in the spring of 1922.

Conclusions:

- Major snowmelt floods in the Basin are caused by a combination of above normal fall precipitation, above normal winter precipitation, and a rapid melt rate, which can be enhanced by spring rainfall.

- Wet conditions in the fall increase the likelihood of a large snowmelt flood the following spring by reducing available wetland storage, reducing soil moisture capacity, and reducing snowmelt infiltration into the soil due to an impermeable frozen soil layer.

- Drainage works in the Basin did not contribute significantly to the observed 1995 flood peaks and volumes.

- During major flood events Lake of the Prairies significantly reduces peak flow rates and water levels downstream of Shellmouth Dam from what would occur if the dam and reservoir not been in place.

Recommendation 1:

Water management agencies should expand efforts to promote awareness of the hydrologic processes that lead to large floods, as well as the effect of water control projects on flow rates and water levels. (Education and Demonstration)

8.2 Wetland Drainage

Findings:

Producers feel compelled by climatic conditions in the Basin and the economics of current agricultural production to minimize input costs, increase efficiencies of input application and field operations, maximize cultivated area, and increase crop options. These pressures have resulted in the current level of wetland drainage activity by agricultural producers.

Each province has legislated authority to regulate drainage. Each has also established local bodies to develop and maintain drainage works. However, organized works represent only a small proportion of drainage activity in the Basin. Even though extensive legislation exists, unauthorized drainage efforts far exceed licensed and/or organized drainage works.

Two databases on wetland size and distribution were available to the Study. Each was developed for specific applications and worked well for their intended uses. The Committee focused on the Western Grains Transition Payment Program (WGTPP) data base alone because there were unresolvable technical issues in combining the Ducks Unlimited wetland database with the WGTPP upland covers. In using the WGTPP database alone, the DFCC recognized that temporary and seasonal wetlands were under-represented.

The WGTPP data base shows that nearly six percent of the Basin area is covered by permanent and semi-permanent wetlands. Small wetlands (less than four hectares in surface area) are most susceptible to drainage. Wetlands that are four hectares or less in size comprise a large percentage of the existing lake and wetland numbers but represent only a small percentage of the Basin wetland area. Based on the relationship between wetland area and volume developed using wetlands in the Basin and the WGTPP wetland coverage, the small wetlands were also

found to provide only a relatively small proportion of the total wetland storage in the Basin and the total wetland storage potential was found to be small relative to large runoff events.

There was not adequate information available on historic wetland distribution to allow comparison with current distribution and to determine wetland loss across the Basin. However, studies were available for select areas in the Basin which showed a range of wetland loss rates but were consistent with other published and accepted general loss values of about a 45 percent reduction for those selected areas. No extrapolation of these studies was attempted as the areas selected were known to be highly impacted by drainage activities and were not likely representative of the Basin as a whole.

The studies show that in those select areas, most of the drainage activities occurred prior to 1980 and most of the efforts since 1980 have been primarily for maintenance and improvements to the existing drainage systems. The drainage complaint process shows that new unauthorized drainage of temporary and seasonal wetlands using contour ditches and V-ditching has continued since 1980 in other areas of the Basin. These activities generally increase following wet years and are most prevalent in areas with a high concentration of undrained wetlands and on lands being incorporated into larger farm units.

At this time, wetland loss can only be determined through manual examination of a time series of air photos for a given location as was done in the three studies reviewed in this report. Where this photo examination has been carried out and a loss of wetlands identified, it is inferred that drainage of wetlands has occurred. However, the drains are not always visible on the air photos and the possibility exists that the loss of some wetlands is due to differences in climatic conditions between the photo sets being compared.

Conclusions:

- Loss of wetlands in the Basin is the result of several factors faced by producers such as economics, crop selection, climate, farm size, and equipment size.

- The current framework for regulating drainage in Saskatchewan and Manitoba is largely ineffective in controlling drainage of small prairie pothole wetlands within a farm unit.

- Changes to legislation and/or substantial additional resources allocated to enforcement are required to address the issue of unauthorized drainage and to regulate the operation of existing drainage works in the Basin.

- Wetland databases offer a range of wetland definitions and are collected at differing times for varying purposes. Database users need to be aware of the wetland definitions used and conditions under which the data was collected.

- Wetland loss has been significant in several areas of the Basin including areas north of Churchbridge and north of Buchanan. Other areas have been less affected. In areas with

a high density of small existing wetlands and proximity to a topographic outlet, there is potential for wetland loss.

- Due to the scale of the Basin, there is no practical, cost-effective method of detecting wetland loss due to drainage at this time.

- A relationship between wetland area and wetland storage volume was developed based on field data available from within the Basin. This relationship can be used in conjunction with remotely sensed data of wetland area to estimate wetland storage volume in a region or watershed.

Recommendation 2:

Provincial governments should establish an effective regulatory framework for drainage which provides the resources and expertise required for proper review and enforcement. (Policy and Legislation, Compliance and Enforcement)

Recommendation 3:

Provincial agencies should continue to monitor developments in remote sensing technology with a view to future application in the detection of wetland drainage. (Monitoring and Assessment)

Recommendation 4:

Research agencies should focus efforts on developing remote sensing technology for application to the detection of wetland drainage in the Canadian Prairies. (Research)

Recommendation 5:

Water and wetland management agencies should collect further field data for very small, shallow wetlands in the Basin to give greater confidence in applying the area-volume relationship in the range of wetlands subject to contour ditching and V-ditching. (Research)

Recommendation 6:

Water and wetland management agencies should define common standards and definitions in the assembly of wetland databases. (Monitoring and Assessment)

8.3 Effect of Wetland Drainage on Basin Hydrology

Findings:

The effect of an individual drainage project or group of projects on the shape and peak of the runoff hydrograph at any location can be assessed using hydraulic and storage routing models in small watersheds. However, the data requirements for such models are prohibitive, thus rendering this approach impractical for application to watersheds of the scale of the Basin.

Conceptual application of hydraulic routing on simple wetland systems found that in years with low or moderate runoff, natural wetlands capture and hold snowmelt runoff which is then subject to evaporation over the following summer. In years where pre-runoff water levels are high in natural wetlands due to carry-over of storage from the previous fall, little of the snowmelt runoff can be stored in the wetlands. The same conceptual application shows that surface drainage of wetlands without control structures will increase runoff volumes and will increase peak flows at least locally in most years. Effects further downstream depend on project location within the larger watershed, number and location of other projects, and the relative timing of natural flows and project outflows. Finally, the conceptual application shows that projects with structural works which can regulate outflows have the ability to minimize downstream effects and to control the timing of peak outflows, in most years.

This Study found no practical method to detect and map historical wetland drainage on a large watershed scale. Without accurate information on the extent of historical drainage activity across the Basin, the Committee was unable to assess the impact of wetland drainage on the runoff regime in the Basin.

Conclusions:

- Natural wetlands retain runoff, much of which will subsequently evaporate. Drainage of wetlands moves runoff into the stream network thus reducing the opportunity for evaporation and increasing runoff volumes.
- The greatest impact of drainage on flows occurs during moderate runoff events. The effect of wetland drainage diminishes for increasingly larger flood events.
- Wetlands that are full in the fall have little storage available to retain snowmelt runoff the following spring.
- In large floods, storage in wetlands is a small percentage of the total volume of flow.
- In general, drainage projects which can regulate outflows will have less effect on downstream peak flows than projects which do not regulate outflows.

- The effects on runoff of individual drainage projects in small watersheds can be analyzed using hydraulic models.
- It is not practical at this time to assess the effects of large numbers of undocumented drainage works using hydraulic models on a watershed the size of the Basin.
- The smaller wetlands in the WGTPP database represent a small proportion of the total wetland storage potential in the Basin.
- At the local level or on a small watershed scale, smaller wetlands may represent a significant proportion of the wetland storage potential.
- Wetland storage upstream of Lake of the Prairies is an important element in Manitoba's flood management. Loss of a significant portion of that upstream storage could have implications on the management of Lake of the Prairies for flood control.

Recommendation 7:

Promote and provide incentives for the retention of existing natural wetlands where those wetlands provide significant benefits in controlling snowmelt runoff into the stream network in most years. (Watershed Management Plans, Best Management Practices, Education and Demonstration, Incentive Programs)

Recommendation 8:

Economic and other factors faced by producers in their decision whether or not to drain wetlands should be considered in the development of environmental, social, or economic programs or policies to address drainage issues. (Policy and Legislation, Incentive Programs)

Recommendation 9:

Proposed drainage projects should be planned and approved within the context of a local watershed plan which considers the impacts at downstream locations. (Watershed Management Plans)

Recommendation 10:

Where drainage projects are approved, promote the construction of works such as backflood projects or controlled drainage to minimize downstream effects. Local watershed plans should include operating guidelines for controlled drainage works and backflood projects so that downstream damages are minimized. (Best Management Practices, Watershed Management Plans)

Recommendation 11:

Continue research and development of practical watershed modeling tools which can be used by provincial regulatory agencies to assess the impact of drainage projects on watershed hydrology. (Research)

8.4 Land Cover Change

Findings:

The landscape of the Basin has undergone great change since settlement. Where once the Basin was a natural prairie and parkland, now the most prevalent land use in the Basin is for annual crops. From the Statistics Canada Census information dating back to the 1950s, improved area has increased from 56 percent to 77 percent of the reported land area. Unimproved area has fallen from 44 percent to 23 percent. This unimproved area is comprised primarily of woodlands, native grasslands, and wetlands.

A comparison of mapped wooded area in the 1950s with that mapped more recently shows that many small, isolated woodland stands have been eliminated, while larger stands have been less affected. Various sources of data on wetland numbers, unimproved land area, and improved land area over time indicate the rate of conversion of unimproved land into agricultural production has slowed over the past two decades.

Conclusions:

- Substantial changes in land cover in the Basin have occurred.
- The rate of change in land cover in the Basin has slowed over the past two decades as the limit of the area which can practically be developed is approached.

8.5 Effect of Land Cover Change on Basin Hydrology

Findings:

Hydrologic analysis of streamflows in the Basin indicates that runoff has been increasing with time. Although regression analysis did show a high correlation with land use change, the Committee was unable to determine the cause of the apparent increasing trend in runoff using streamflow records alone. A significant limitation was that many land cover changes pre-date the inception of most hydrometric stations in the Basin.

Prairie-based research results suggest that over-winter stubble retention on a watershed basis and/or conversion to permanent cover is likely to reduce overall runoff volumes and spring peak flow rates. Over-winter stubble and permanent cover tend to hold snow in place better, improve

infiltration, and slow the overland flow of water. Recent trends away from summer fallow on cropped land and reversion of cropped land to permanent cover are believed to be offsetting to some degree the apparent trend toward increased runoff volumes.

The application of the SLURP model was successful in modeling flows for larger watersheds with the current land cover base (1995-97). In addition, the Study demonstrated that GIS methods are able to generate land cover data required for semi-distributed hydrologic models and also demonstrated the successful application of digital elevation modeling in generating the topographic data required for hydrologic modeling.

The modeling was not successful in determining the effect of land cover change on Basin runoff. The Committee believes better results may be achieved with more realistic representation of the contributing drainage area, simulation of wetland storage, improvements to the simulation of prairie runoff processes, and adequate time and resources to calibrate the model parameters.

Land cover has an effect on the redistribution of snow by wind within a watershed. Research has shown that stubble management affects snow distribution. Models such as SLURP, when calibrated and functioning properly, should be able to determine how various land covers affect snow redistribution and consequently spring snowmelt and runoff for a large watershed in the Prairie Parkland. The loss of smaller woodlands may affect the Basin hydrology by increasing snow transport and reducing the number and frequency of areas where blowing snow may be collected over the course of the winter.

Conclusions:

- Changes in Basin land cover, including loss of wooded area, loss of wetlands, conversion from grass to cultivation, and road development, have resulted in increased runoff volumes in the Basin over what would have occurred naturally.
- It is not possible to determine the effect on Basin runoff of changes to individual land covers from an examination of recorded streamflow data alone.
- It is not possible to determine the effect on Basin hydrology of changes to individual land covers using the SLURP model with the current suite of six land covers as currently calibrated.
- The SLURP model satisfactorily simulated observed flows for 1995-1997 at five locations within the Basin, all of which have large drainage areas.
- Simulation of observed flows at locations with smaller drainage areas was not satisfactory, likely due to the averaging of land cover parameters for the entire Basin.
- The Prairie Blowing Snow and the Frozen Soil Infiltration routines added to the SLURP model for this application significantly improved model performance.

Recommendation 12:

Promote and provide incentives which encourage producers to adopt agricultural practices such as conservation tillage and permanent cover programs which retain or re-establish perennial cover as means to reduce runoff rates and volumes. (Best Management Practices, Education and Demonstration, Incentive Programs)

Recommendation 13:

Research agencies should continue investigations into the relationship between snowmelt runoff and agricultural practices such as stubble management and conversion to permanent cover, and clearing of bush. Specifically, two similar small watersheds in the Basin should be identified and monitored, one receiving intensive stubble management and conversion treatment while the other remains as representative of current agricultural practices. (Research)

Recommendation 14:

An inter-agency working group should be formed to continue assessing the hydrologic effects of wetland drainage and land cover change in the Basin with the knowledge base developed in this Study. (Monitoring and Assessment)

Recommendation 15:

Research agencies should develop watershed models with improved simulation of hydrologic processes on the Canadian Prairies such as variable contributing area and wetland storage. (Research)

8.6 Flooding

Findings:

While flood events are largely natural phenomena, flood damages result when inappropriate land uses or developments are located in flood-prone areas. In addition to agricultural land adjacent to streams and waterbodies throughout the Basin, flood-prone areas in the Basin also include various lake and reservoir shorelines and several small communities.

Conclusions:

- There are a number of flood prone areas in the Basin where there are inappropriate developments or land uses.

- Ensuring compatible land uses and only allowing appropriate new developments occur in flood prone areas will minimize long-term risks and costs of flood damage.

Recommendation 16:

Provincial agencies should ensure that future development does not occur within flood prone areas through a review of the processes for subdivision approvals and granting of building permits. (Policy and Legislation)

Recommendation 17:

Programs should be developed to encourage the adoption of compatible land use practices in flood prone areas in order to reduce damages to agricultural lands and urban developments located adjacent to streams and waterbodies. (Incentive Programs)

Recommendation 18:

Studies should be conducted to determine if engineering works are a practical method of reducing the risk of flood damages to existing developments in flood prone areas. (Monitoring and Assessment)

8.7 Lake Management

Findings:

Multiple interests in the use of lakes and reservoirs have resulted in conflicts over water level management and the operation of outlet control structures. While specific effects for individual lakes were not evaluated, this Study has found a trend of increasing runoff volumes in the Basin. Where there is limited outlet or downstream channel capacity, water level management is made more difficult by increased flow volumes into the lakes.

Conclusions:

- In general, drainage of wetlands located upstream of lakes and reservoirs will increase runoff volumes into those waterbodies with the impact of reducing operating flexibility for reservoirs as determined when the reservoirs were created.

Recommendation 19:

Both structural and non-structural measures should be investigated to improve operational flexibility of the reservoirs in the Basin. (Research)

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Appendix I

ASA Physiographic Parameters Used in SLURP

ASA Physiographic Parameters Used in SLURP

ASA #4: Whitesand River near Sheho

Land Cover	To-Stream			In-Stream			Average Elevation (m)
	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	
Water	0.800	0.749	1	29.3	7.66	22	531
Crop	4.08	3.09	11	37.8	13.0	50	570
Grass	2.50	1.95	8	23.0	10.3	21	537
Shrub	3.01	2.74	9	25.8	14.1	28	545
Wetland	2.56	2.48	7	27.6	1.08	32	547
Bush	3.30	2.83	10	27.9	14.0	30	549

ASA#10: Whitesand River to Theodore Reservoir

Land Cover	To-Stream			In-Stream			Average Elevation (m)
	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	
Water	0.077	0.059	3	5.29	3.17	3	496
Crop	4.20	5.46	17	27.1	10.4	55	561
Grass	2.92	3.27	12	24.6	9.37	39	541
Shrub	3.90	4.22	15	27.7	9.18	51	556
Wetland	5.61	7.28	20	27.5	9.89	57.0	567
Bush	2.83	3.7	15	22.8	10.9	36	541

ASA #15: Whitesand River to Confluence with Yorkton Creek

Land Cover	To-Stream			In-Stream			Average Elevation (m)
	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	
Crop	1.57	1.19	14	38.9	17.5	56	547
Grass	1.45	12.7	11	38.0	22.5	60	548
Shrub	1.34	1.28	10	46.5	21.2	80	567
Wetland	1.12	1.38	7	39.9	21.7	63	548
Bush	1.40	1.32	10	34.3	23.6	53	540

ASA # 20: Willow Brook

Land Cover	To-Stream			In-Stream			Average Elevation (m)
	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	
Crop	1.91	1.64	5	32.6	19.3	92	628
Grass	1.91	1.34	6	39.7	15.1	113	650
Shrub	1.71	1.31	7	43.3	11.4	118	656
Wetland	1.77	1.57	5	37.8	16.7	106	643
Bush	1.71	1.32	6	41.2	13.7	117	654

ASA #17: Cussed Creek

Land Cover	To-Stream			In-Stream			Average Elevation (m)
	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	
Crop	1.91	1.76	7	50.8	28.8	75	559
Grass	1.62	1.50	6	61.1	28.2	96	578
Shrub	1.49	1.35	8	71.4	24.6	120	606
Wetland	1.72	1.81	5	64.3	31.7	103	586
Bush	1.64	1.48	7	65.4	30.5	106	590

ASA #18: Yorkton Creek

Land Cover	To-Stream			In-Stream			Average Elevation (m)
	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	
Water	0.331	0.290	1	52.6	11.5	29	509
Crop	1.56	1.23	5	67.0	32.8	54	538
Grass	1.28	1.05	3	56.9	22.8	39	522
Shrub	1.45	1.22	4	74.4	25.0	56	540
Wetland	1.23	1.14	3	61.9	34.0	48	531
Bush	1.72	1.31	5	69.1	37.5	570	543

ASA #6: Spirit Creek

Land Cover	To-Stream			In-Stream			Average Elevation (m)
	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	
Crop	3.78	2.93	9	11.3	4.95	40	542
Grass	2.65	1.56	17	6.85	2.82	23	532
Shrub	5.12	3.39	11	13.7	4.17	50	553
Wetland	4.04	3.02	12	11.0	5.60	39	543
Bush	5.28	3.39	11	14.1	3.67	52	555

ASA #8: Good Spirit Lake

Land Cover	To-Stream			In-Stream			Average Elevation (m)
	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	
Water	0.966	0.684	2	7.73	3.33	2	484
Crop	4.14	2.80	8	24.0	9.55	21	509
Grass	3.80	2.80	7	18.5	10.1	16	504
Shrub	4.13	3.33	7	20.0	11.5	20	506
Wetland	2.89	2.72	5	16.2	10.1	11	496
Bush	3.53	2.86	6	16.4	10.5	15	501

ASA #11: Whitesand River near Canora

Land Cover	To-Stream			In-Stream			Average Elevation (m)
	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	
Water	0.684	0.458	2	31.7	1.50	5	480
Crop	2.35	1.96	6	44.9	23.3	24	503
Grass	2.18	2.18	6	42.0	21.3	20	498
Shrub	2.23	2.27	5	44.8	20.4	20	497
Wetland	1.71	1.65	4	51.3	23.3	29	505
Bush	2.53	2.21	7	43.1	22.1	20	499

ASA #1: Assiniboine River near Sturgis

Land Cover	To-Stream			In-Stream			Average Elevation (m)
	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	
Water	2.83	2.51	8	44.7	28.2	64	575
Crop	5.37	4.63	27	27.0	12.7	28	558
Grass	5.03	4.16	30	34.5	13.3	40	573
Shrub	4.20	4.37	22	30.2	14.9	34	559
Wetland	5.81	3.72	27	50.1	17.4	66	596
Bush	5.93	3.99	30	48.3	17.1	63	597

ASA #5: Crooked Hill Creek

Land Cover	To-Stream			In-Stream			Average Elevation (m)
	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	
Crop	1.98	1.58	4	24.0	12.4	28	512
Grass	1.64	1.20	4	14.1	10.5	12	496
Shrub	2.05	1.57	5	33.2	9.99	44	528
Wetland	1.95	1.51	4	16.5	11.6	16	500
Bush	2.13	1.43	5	35.5	11.2	50	535

ASA # 2: Assiniboine River at Kamsack

Land Cover	To-Stream			In-Stream			Average Elevation (m)
	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	
Crop	2.04	1.52	14	62.4	32.7	54	501
Grass	1.36	1.23	13	57.6	27.8	43	490
Shrub	1.66	1.75	12	68.2	29.2	58	503
Wetland	1.65	1.46	9	62.1	28.6	59	502
Bush	2.39	1.94	23	41.0	32.1	97	554

ASA #9: Little Boggy Creek

Land Cover	To-Stream			In-Stream			Average Elevation (m)
	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	
Crop	2.09	1.63	31	8.99	3.91	62	539
Grass	1.42	1.25	35	14.1	7.85	90	571
Shrub	2.04	1.51	39	17.1	8.42	111	596
Wetland	2.19	1.49	34	19.7	10.0	146	626
Bush	1.76	1.27	47	19.1	9.13	130	623

ASA #16: Stony Creek near Kamsack

Land Cover	To-Stream			In-Stream			Average Elevation (m)
	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	
Crop	2.53	2.85	6	25.6	11.3	33	522
Wetland	3.07	2.77	4	28.7	10.2	35	523
Bush	2.74	2.75	6	27.8	10.1	33	523

ASA #7: Shell River near Roblin

Land Cover	To-Stream			In-Stream			Average Elevation (m)
	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	
Water	1.80	2.14	7	80.5	18.2	127	674
Crop	1.80	1.04	38	25.7	12.6	46	624
Grass	1.66	1.38	37	22.4	17.3	42	619
Wetland	2.70	2.05	19	74.6	19.4	112	671
Bush	2.49	1.88	29	61.3	24.4	95	664

ASA #14: Shell River near Inglis

Land Cover	To-Stream			In-Stream			Average Elevation (m)
	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	
Crop	2.73	2.14	46	29.5	23.5	89	578
Grass	2.32	2.15	44	40.8	25.7	78	565
Wetland	5.52	3.55	52	48.9	31.4	108	602
Bush	3.92	3.42	51	45.4	29.0	93	586

ASA #131: Local Area East of Lake of the Prairies

Land Cover	To-Stream			In-Stream			Average Elevation (m)
	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	
Crop	2.99	1.90	47	56.3	22.5	74	550
Grass	2.65	2.11	44	55.2	23.1	71	545
Shrub	1.43	1.55	42	57.9	17.5	50	522
Wetland	2.90	2.38	24	67.9	18.0	98	551
Bush	3.24	2.45	46	50.0	28.9	68	543

ASA #132: Local Area West of Lake of the Prairies

Land Cover	To-Stream			In-Stream			Average Elevation (m)
	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	
Crop	3.61	2.75	23	70.9	31.5	50	502
Grass	3.22	2.64	42	53.9	27.9	32	502
Shrub	3.02	2.82	36	51.0	19.2	34	499
Wetland	5.01	3.12	18	67.5	27.5	61	508
Bush	3.17	2.92	37	48.5	29.2	36	502

ASA #19: Conjuring Creek near Russell

Land Cover	To-Stream			In-Stream			Average Elevation (m)
	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	
Crop	0.804	0.606	4	12.9	7.07	37	598
Grass	0.929	0.736	3	9.96	6.20	24	584
Wetland	1.10	0.845	7	12.3	8.48	36	600
Bush	1.55	0.793	12	19.1	6.29	64	634

ASA #22: Smith Creek

Land Cover	To-Stream			In-Stream			Average Elevation (m)
	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	
Crop	4.42	3.23	7	26.2	10.2	20	524
Grass	4.87	4.37	6	32.2	8.70	24	527
Shrub	3.40	3.08	6	26.1	10.2	20	523
Wetland	4.54	3.71	6	30.7	7.66	24	527
Bush	4.58	2.96	8	25.4	10.4	20	524

ASA #241: Local Area East Side above Russell

Land Cover	To-Stream			In-Stream			Average Elevation (m)
	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	
Crop	2.94	2.29	31	25.4	11.6	116	556
Grass	2.08	2.01	26	19.3	11.3	81	517
Shrub	0.614	0.438	14	16.8	2.71	2	425
Wetland	3.33	2.36	26	27.2	11.7	118	553
Bush	2.25	2.47	28	19.5	11.5	76	513

ASA #242: Local Area West Side above Russell

Land Cover	To-Stream			In-Stream			Average Elevation (m)
	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	
Crop	3.67	2.58	16	32.7	13.4	85	510
Grass	2.50	2.15	22	26.1	17.0	65	496
Shrub	2.97	2.54	26	24.1	13.8	60	495
Wetland	3.61	2.52	14	33.9	13.1	86	509
Bush	2.66	2.42	34	19.3	14.4	47	490

ASA #232: Local Area West Side above St. Lazare

Land Cover	To-Stream			In-Stream			Average Elevation (m)
	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	
Crop	3.21	2.70	8	56.7	15.2	105	507
Grass	1.94	2.14	19	32.8	16.5	70	482
Shrub	2.57	2.25	5	44.9	18.3	99	497
Wetland	3.24	2.89	6	57.4	19.3	102	502
Bush	1.84	2.00	21	36.3	21.9	67	481

ASA #231: Local Area East Side above St Lazare

Land Cover	To-Stream			In-Stream			Average Elevation (m)
	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	Average Distance (km)	Distance Std Dev (km)	Avg. Change in Elevation (m)	
Crop	4.57	3.54	45	46.1	16.3	108	547
Grass	3.70	3.53	36	44.6	17.4	97	528
Wetland	4.06	3.56	27	48.5	15.9	118	539
Bush	3.58	3.76	47	38.2	16.8	73	513